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A DATA REDUCTION PROGRAM FOR
A ROCKETSONDE TEMPERATURE SENSOR

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ABSTRACT

A mathematical model for obtaining *air temperature* from a standard ARCASONDE bead, wire, film temperature sensor and its radar track is developed in this thesis. In addition, *pressure* and *density* of the atmosphere, and *horizontal winds* are computed. While this model has an unrestricted altitude range, the rocketsonde flights used generally vary from 20 to 90 kilometers. The temperature errors encountered in these flights become large at high altitudes, with aerodynamic heating and thermal conduction being the largest. Aerodynamic heating is due mainly to the high speed of the rocket and the initial altitudes. The thermal conduction model describes a bead and film, which respond with a dynamic lag to temperature changes, connected by a wire which responds instantaneously. The temperature corrections due to radiation and electrical heating are relatively small at altitudes below 50 kilometers. Approximate values of radiation heating in the sensor can be computed from Lambert's Cosine Law. The large uncertainties associated with the radiation inputs to the sensor are due mainly to the large uncertainties in the absorptivity of the sensor.

A computer program is developed for the UNIVAC 1108 to take rocketsonde data and produce air temperature, pressure, density, and horizontal winds. A real rocketsonde flight at Wallop's Island, Virginia on September 5, 1967 at 1516 Z with an altitude range of 25 to 50 kilomemters serves as an illustration of this program.

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GLOSSARY

A	total or surface area of sensor - m^2
a	albedo of the earth-atmosphere system
C	specific heat of the sensor - J/(kg°K)
C_p	specific heat of the atmosphere at constant pressure
C_s	speed of sound - m/s
DF	drag force - N
D	diameter or thickness of the sensor - m
ε	emissivity
F	long wave radiation flux density - W/m^2
f	ratio of cross section to total surface area
g	gravity - m/s^2
h	convection coefficient - $W/\left(m^2 {}^\circ K\right)$
I	short wave radiation flux density
I_0	solar constant
J	radiation intensity - $W/\left(m^2\ sr\right)$
i	angle of incident radiation
δ	angle of emitting radiation
k	thermal conductivity - W/(m°K)
L	Mean free path - m
ζ	station latitude
ℓ	length of sensor component - m
p	pressure - N/m^2
Q	heat flux into the sensor - W/m^2

R	distance between the sensor and radiation source - m
R_D	gas constant for dry air - J/(kg°K)
Re	mean radius of the earth - m
r	recovery factor
S	distance along a sensor component - m
T	temperature - °K
t	time - s
τ	time constant - s
V	air speed of the sensor - m/s
v	volume - m^3
W	electric heating referred to thermistor surface area - W/m^2
W_x	east wind - m/s
W_y	south wind - m/s
Ω	angular velocity of the earth
x	east horizontal direction - m
y	south horizontal direction - m
z	altitude - m
ρ	density - kg/m^3
σ	Stefan-Boltzmann constant - $W/\left(m^2 {}^\circ k^4\right)$
α	absorptivity
λ	decay length - m
μ	viscosity - kg/(m s)

Subscripts:

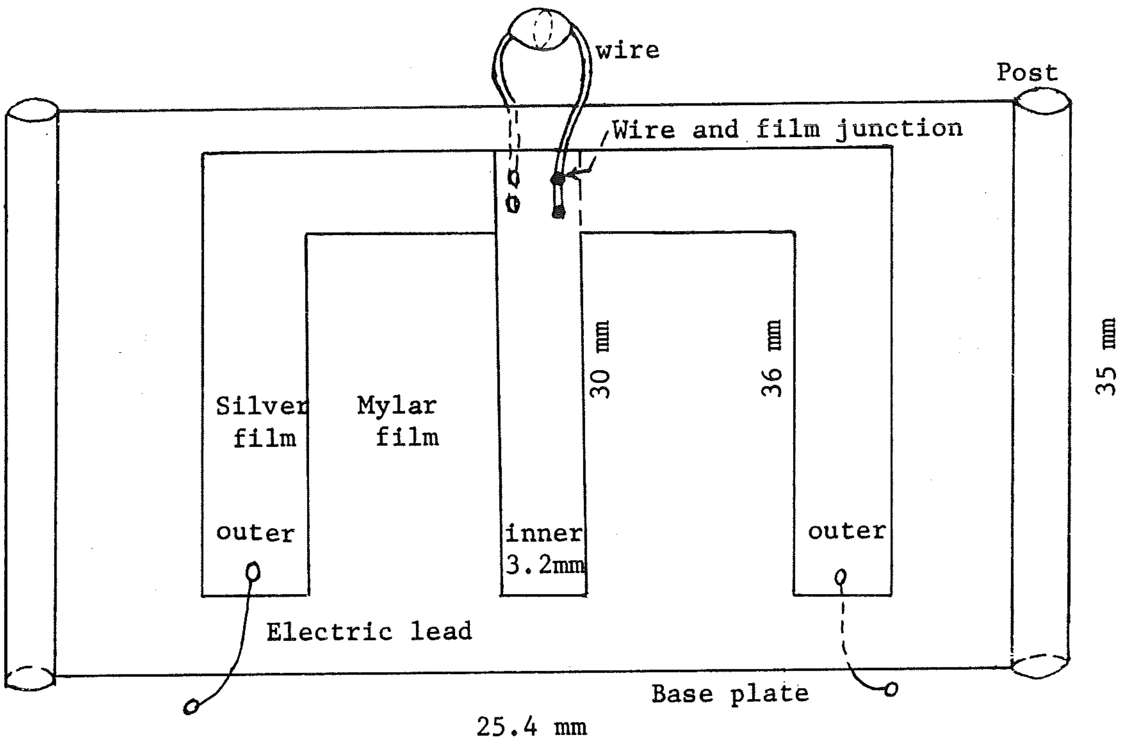
a	average
Ag	silver film
Ag-My	silver-mylar laminar film
b	thermistor bead
c	conduction
e	equilibrium or steady-state condition
f	film
i	incident
ℓ	long wave radiation
My	mylar
r	total radiation
s	short wave radiation
w	wire
1	earth and atmosphere
2	instrument package

I. INTRODUCTION AND STATEMENT OF THE PROBLEM

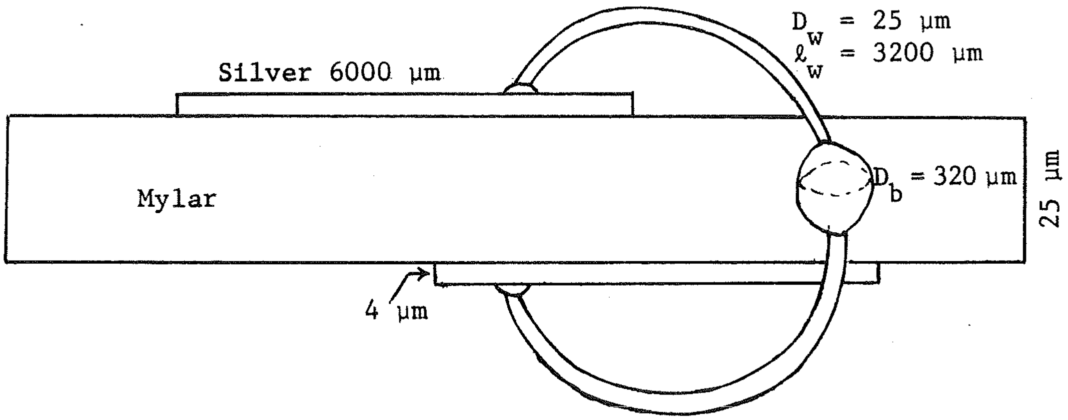
The purpose of this paper is to develop a mathematical model which will calculate atmospheric temperatures, pressures, densities and horizontal wind distributions of the upper atmosphere from rocketsonde measurements. Data from the rocketsonde flight at Wallop's Island, Virginia on September 5, 1967 at 1516 Z provides the basis for the discussion of the results. The measuring instrument used is the standard ARCASONDE 1A temperature sensor carried by the ARCAS rocket to altitudes of fifty to seventy kilometers. The sensor temperature and radar track are recorded digitally on magnetic computer tapes as the rocketsonde descends by parachute back to earth. A computer program has been developed which will calculate atmospheric parameters from the rocketsonde data.

The ARCASONDE 1A temperature sensor consists of an aluminum coated metallic oxide thermistor bead attached by two platinum-iridium wires to a silver film deposited on a mylar substrate. The mathematical model adopted to describe this sensor uses the bead, wire, and film as integral components. A schematic representation of this sensor is shown in the following figure.

In the process of measuring the air temperature, the sensor is subject to heat transfer with the environment. These heat inputs are radiation from the sun, the earth-atmosphere system, and the instrument package, as well as aerodynamic, electrical, and radiofrequency heating. Sensor lag and thermal conduction due to heat exchange with the wires



Front view



Leading edge of the film

Fig. 1. ARCASONDE bead-wire-film sensor.

and film are additional sources of complication.

In regard to application, rocketsonde data can be used to measure atmospheric parameters from 20 to 90 kilometers in a region where satellite data and radiosonde information are not available on a routine basis. If the rocketsonde stations are sufficiently dense and soundings are made often enough, synoptic charts can be made to supplement existing radiosonde charts. These charts would contain geostrophic and thermal winds as well as diurnal and seasonal variations of the atmosphere.

II. PHYSICAL FACTORS AFFECTING ROCKETSONDE MEASUREMENTS

1. Convection and Aerodynamic Heating

The heat flux between a stationary sensor and the surrounding air is related to the difference between the air and sensor temperatures by the first law of thermodynamics, i.e.,

$$\rho c \frac{v}{A} \cdot \frac{\partial T}{\partial t} = h\left(T_{air} - T\right)\left[W/m^2\right] \tag{1}$$

Because the sensor is moving relative to the air at speed V, air is compressed and heated at the sensor. The resulting increase in the sensor temperature due to this aerodynamic heating is

$$\Delta T = \frac{rV^2}{2C_p} \; [°K] \tag{2}$$

The recovery factor, r, corrects for nonadiabatic friction and kinetic effects of the surrounding air.[21]

By combining the effect of aerodynamic heating (Eq. 2 with Eq. 1), the convective heat transfer equation follows:

$$\rho c \frac{v}{A} \frac{\partial T}{\partial t} = h\left(T_{air} + \frac{rV^2}{2C_p} - T\right) \tag{3}$$

The form of the equation for the convection coefficient, h, and recovery factor, r, depends on the altitude, air speed, and characteristic length of the sensor component. Assuming the sensor is in steady state ($\partial T/\partial t = 0$), the sensor temperature can be calculated from Eq. 3 to give

$$T_r = T_{air} + \frac{rV^2}{2C_p} \tag{4}$$

The recovery temperature, T_r, is the equilibrium temperature of an isolated object moving with air speed, V, assuming no radiation inputs.

2. Radiation

Radiation heating of the ARCASONDE sensor is inherent in the measurement of air temperature using rocketsonde data. The sources of radiation and approximate calculations of the heating effect will be considered in this section. The total radiation received by the spherical thermistor in the ARCASONDE sensor is due to the following sources:

1. Direct (parallel) sunlight: I_1
2. Reflected (diffuse) solar energy from the earth and atmosphere: I_2
3. Reflected shortwave radiation from the earth and atmosphere which is reflected from the instrument package: I_3
4. Direct long wave radiation from the earth and atmosphere: F_1
5. Long wave radiation from the instrument package: F_2
6. Long wave radiation from the earth and atmosphere reflected by the instrument package: F_3

Disregarding multiple reflections between the earth, thermistor, and instrument package, the total radiation input is given as the sum of the individual components.

$$Q = \left(I_1 + I_2 + I_3\right)\alpha_S + \left(F_1 + F_2 + F_3\right)\alpha_L \; \left[W/m^2\right] \tag{5}$$

In reality, the absorptivity (α) and reflectivity ($1 - \alpha$) are not known exactly, but are assumed to be spectrally averaged quantities in the long wave region $\left(\alpha_L, 1 - \alpha_L\right)$ and short wave region $\left(\alpha_S, 1 - \alpha_S\right)$.

The basic radiation laws for a spherical receiver realized by the thermistor bead in the case of long wave radiation will be derived next. Here we work with a black thermistor where the absorption is taken into account in Eq. 5.

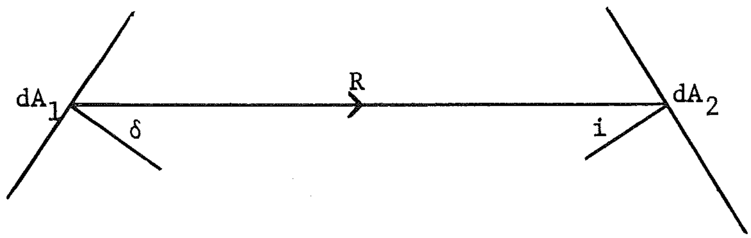


Fig. 2. Geometrical configuration of receiving and emitting surfaces.

According to Lambert's Cosine Law of Photometry, the radiation energy due to an elemental surface dA_1 emitted at an angle δ and received by another elemental surface dA_2 at an incidence angle i is

$$dQ = J \frac{dA_1 \cos \delta \, dA_2 \cos i}{R^2} \text{ [Watt]} \tag{6}$$

assuming R is much larger than the dimensions of the elemental areas. The important geometrical quantities involved in Eq. 6 are

1. the solid angle subtended by the emitting surface, dA_1, as viewed by dA_2:

$$\frac{dA_1 \cos \delta}{R^2} \text{ [sr]}$$

2. the apparent radiation receiving surace:

$$dA_2 \cos i$$

3. the intensity of the emitted radiation:

$$J \left[W/\left(m^2 \text{ sr}\right)\right]$$

Since the receiving element (thermistor) is a spherical surface, $dA_2 \cos i$ can be replaced by its cross sectional area, $\pi D_b^2/4$. The ratio of the cross section to the total surface area of the thermistor is $f = 1/4$. Equation 6 can be written as an average flux density for the thermistor as follows:

$$\frac{dQ}{\pi D_b^2} = J \cdot f \, dA_1 \frac{\cos \delta}{R^2} \left[\frac{W}{m^2}\right] \tag{7}$$

This equation can be used to calculate radiative flux densities received by the thermistor from the earth and instrument package as illustrated in Fig. 3. Consider radiation from a small black element of the earth's surface, which can be considered as an infinitely far extended horizontal plane of temperature T_1. In the absence of the atmosphere, the flux density intercepted by the spherical thermistor and distributed over its total surface area is obtained from Eq. 7.

$$dF_1 = \frac{dQ_1}{\pi D_b^2} = \frac{\sigma T_1^4}{\pi} f \frac{x \, dx \, d\phi}{R^2} \cos \delta \tag{8}$$

Simplifying Eq. 8 and taking into account the geometry of Fig. 3, one obtains for flux density from the earth's surface

$$F_1 = \frac{\sigma T_1^4}{2} \int_0^{\pi/2} \sin \delta \, d\delta \tag{9}$$

Taking into account the earth's atmosphere, and denoting by J_λ the

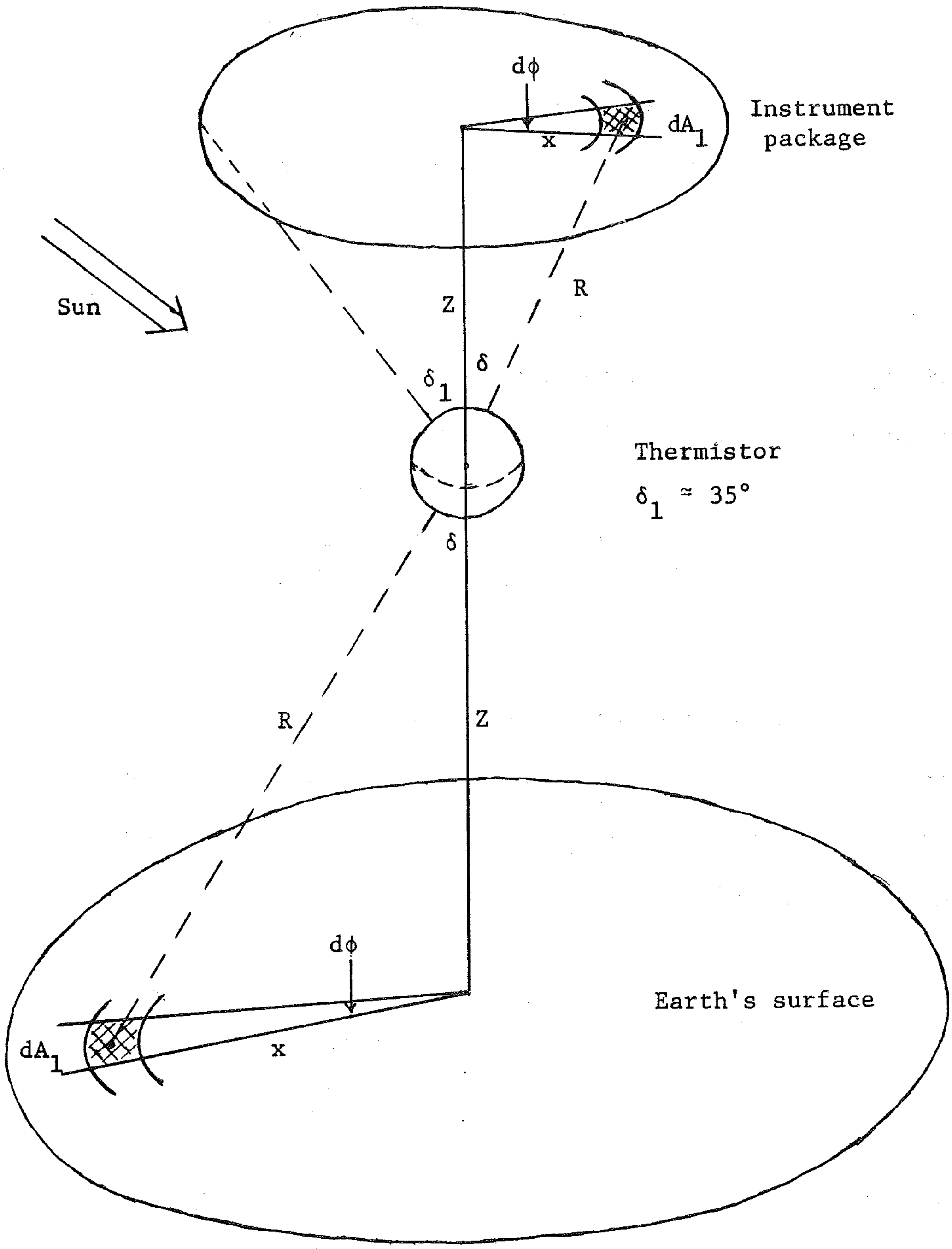


Fig. 3. Earth and instrument package as radiation sources.

monochromatic intensity received at the spherical thermistor, the radiant flux density (Eq. 9) can be written more generally as

$$F_1 = \frac{\pi}{2} \int_0^\infty d\lambda \int_0^{\pi/2} J_\lambda(\delta) \sin \delta \, d\delta \tag{10}$$

Radiation flux from the instrument package with a temperature T_2 and absorptivity α_{L2} can be obtained from Eq. 9 due to the similar geometrical relationship (see Fig. 3) as the function

$$F_2 = \frac{\sigma \alpha_{L2} T_2^4}{2} \left(1 - \cos \delta_1\right) \tag{11}$$

The instrument package also receives long wave radiation from the earth and it's atmosphere. The flux density incident on the base plate of the instrument package, assuming it is oriented essentially parallel to the earth's surface, is

$$F_i = 2\pi \int_0^\infty d\lambda \int_0^{\pi/2} J_\lambda(\delta) \cos \delta \sin \delta \, d\delta \tag{12}$$

Based on the assumption of diffuse reflection of the instrument package, the long wave illumination of the thermistor due to this reflected energy is

$$F_3 = \frac{F_i}{2}\left(1 - \cos \delta_1\right)\left(1 - \alpha_{L2}\right) \tag{13}$$

Thus, from this analysis one is able to obtain approximate values for the long wave component of radiation flux density onto the thermistor.

Basic formulas for short wave radiation received by the thermistor will be obtained next. For this particular rocketsonde flight, the zenith angle of the sun (dependent on latitude, time, and date) is about 51 degrees;[18] therefore, direct solar energy is not screened off from the thermistor by the instrument package and parachute. The direct short wave flux density can be written in terms of the solar constant, I_0, as follows:

$$I_1 = I_0 \; f \cos \phi \tag{14}$$

where ϕ is the angle between the sun and the vertical to the sensor component. For the case of the thermistor, ϕ is equal to zero. It is assumed that reflected sunlight from the earth and atmosphere does not depend on any geometrical relationships, i.e., it is uniformly reflected. At rocketsonde altitudes, the assumed uniformly reflected sunlight occurs above most of the atmosphere and clouds. Thus, the reflected shortwave radiative intensity is $I_0 \; a/\pi$, where a stands for the total albedo of the earth-atmosphere system. The short wave radiation flux density received directly by the thermistor from the earth-atmosphere system is given by

$$I_2 = I_0 \, a/2 \tag{15}$$

The short wave flux density reflected from the earth and atmosphere and received by the base plate of the instrument package is obtained using Eq. 12.

$$I_i = I_0 \, a \tag{16}$$

This short wave energy uniformly reflected from the instrument package and received by the thermistor is

$$I_3 = \frac{I_0 \, a}{2} \left(1 - \alpha_{S2}\right)\left(1 - \cos \delta_1\right) \tag{17}$$

Equation 5 for total flux density received by the thermistor can now be written as follows:

$$Q = \frac{I_0}{2}\left[\frac{1}{2} + a + \left(1 - \alpha_{S2}\right)\left(1 - \cos \delta_1\right) a\right]\alpha_S$$
$$+ \left[F_1 + \left(\frac{\sigma\alpha_{L2} \, T_2^4}{2} + \left(1 - \alpha_{L2}\right) F_i\right)\left(1 - \cos \delta_1\right)\right]\alpha_L \tag{18}$$

Some of the parameters used in calculating the radiation flux density are

1. solar constant I_0: the average value is 1396 W/m^2, with major changes due to seasonal variations (± 3.4 percent)

$$I_0 = 1396 \pm 47.5 \ W/m^2$$

as taken from the Handbook of Geophysics and Space Environments.[13]

2. earth-atmosphere albedo a: the average albedo can be determined by using Angstrom's formula[9] and estimating the amount and type of cloud cover.

$$a = .17 + .34\ C \ , \ C = \text{tenths of cloud cover}$$

Estimating a 75 percent cirrostratus cloud cover, based on a surface synoptic map published by the U. S. Weather Bureau on September 5, 1967 at 1:00 a.m. EST for the area surrounding the rocketsonde station, the albedo according to Angstrom's formula is

$$a \approx .43 \pm .09$$

A 20 percent variation in albedo is assumed[20] due to uncertainties in the amount and type of cloud cover.

3. sensor absorptivities: values of the absorptivities of the sensor components (see Appendix C) along with estimated uncertainties which are used in the flux calculations are

listed below.

	Thermistor[17]	Wire[17]	Ag-My Film (Appendix C)	Instrument Package[1]
Short Wave	.16 ± .06	.19 ± .08	.05 ± .02	.80 ± .10
Long Wave	.10 ± .01	.10 ± .01	.51 ± .20	.80 ± .10

The variable condition of the surface of the sensor components contributes to large uncertainties in the above absorptivities.[23]

4. An assumed temperature of the instrument package is $T_1 \approx 280°K$ which is above ambiant air temperature due to aerodynamic heating of the high speed rocket.

Values of long wave radiation from the earth-atmosphere system, F_i, arriving at a flat plate parallel to the earth's surface have been estimated by Zdunkowski.[29] The computations are based on the following radiation sources:

1. the cirrostratus cloud (at a temperature $T_1 = 243°K$ and altitude of about 10 kilometers based on radiosonde data) is a black body,
2. water vapor, carbon dioxide, and ozone gases in the atmosphere.

A value of F_i for partial cloudiness is estimated from this data by using the linear interpolation formula

$$F_i = (1 - C)F_{clear} + C\, F_{cloud} \tag{19}$$

where F_{clear} and F_{cloud} are the flux densities for a clear and overcast sky, respectively. Based on radiosonde data at the time of the rocketsonde flight

$$F_{clear} = 270\ W/m^2\ ,\ F_{cloud} = 170\ W/m^2$$

Since the radiation flux intecepted by a spherical thermistor and distributed over its entire surface area is one half of that intercepted by a unit area of flat plate parallel to the earth's surface (see Eqs. 10 and 12).

$$F_1(\text{thermistor}) = \frac{F_i(\text{flat plate})}{2} \tag{20}$$

Radiation received by an element oriented vertically to the earth's surface for the case of a wire cylinder and a flat plate can be obtained in a similar fashion. In the absence of the atmosphere, for example, the long wave radiation received by such an element (as shown by Moller)[15] is one half of the radiation received by a flat plate parallel to the earth's surface, i.e.,

$$F_1(\text{vertical element}) = \frac{F_i(\text{flat plate})}{2} \tag{21}$$

In general, these results hold for radiation emitted from the earth-atmosphere system and received by the vertical element.

The radiation flux densities obtained from the analysis in this section are contained in the following table:

TABLE I

Radiation Flux Densities Onto the Bead, Wire, and Film

$$\left[\frac{W}{m^2}\right]$$

	$I_1\alpha_S$	$I_2\alpha_S$	$I_3\alpha_S$	$F_1\alpha_L$	$F_2\alpha_L$	$F_3\alpha_L$	Total Radiation
Thermistor	55.7 ± 22.9	48.0 ± 29.7	1.8 ± 1.9	9.8 ± 1.9	2.6 ± 2.4	1.8 ± 1.1	119.7 ±59.9
Wire	65.5 ± 29.8	67.0 ± 38.0	1.0 ± 1.0	9.8 ± 1.9	1.3 ± 1.2	.2 ± .2	144.8 ±72.1
Ag-My film	27.1 ± 11.8	15.0 ± 9.6	.2 ± .3	49.7 ±19.5	6.6 ± 5.3	.9 ± .8	99.5 ±47.3

The radiation input to a conductively isolated thermistor due to the above radiation sources is approximately

$$Q = 120 \pm 60 \text{ W/m}^2$$

Assuming the thermistor is a grey body of constant emissivity, ε_b, the long wave radiation emitted from a unit area of the thermistor is

$$\sigma\varepsilon_b T_b^4$$

The total radiation input to the bead can now be written as

$$Q - \sigma\varepsilon_b T_b^4 \tag{22}$$

Using the condition of radiative equilibrium, i.e., the radiation input to the thermistor is equal to the radiation emitted

$$Q = \sigma\varepsilon_b T_b^4 ,$$

the thermistor temperature is computed.

$$T_b = \sqrt[4]{\frac{Q}{\sigma\varepsilon_b}} = 378 \pm 50°K \tag{23}$$

This temperature is only realized by a steady-state sensor at high altitudes where radiation is the only significant heat source.

3. Thermal Conduction

Heat transfer into the thermistor by thermal conduction from the wires and film will be discussed next. In general, the heat flux through a plane surface is proportional to the cross sectional area, A, and the temperature gradient, $\partial T/\partial S$.

$$Q_c(S,\ t) = k\ A\ \frac{\partial T(S,\ t)}{\partial S}\ [W] \tag{24}$$

The thermal conduction coefficient, k, is assumed to be an absolute constant, i.e., it doesn't depend on time, t, or distance, S. The particular bead-wire-film system used in the ARCASONDE sensor is illustrated in Fig. 4.

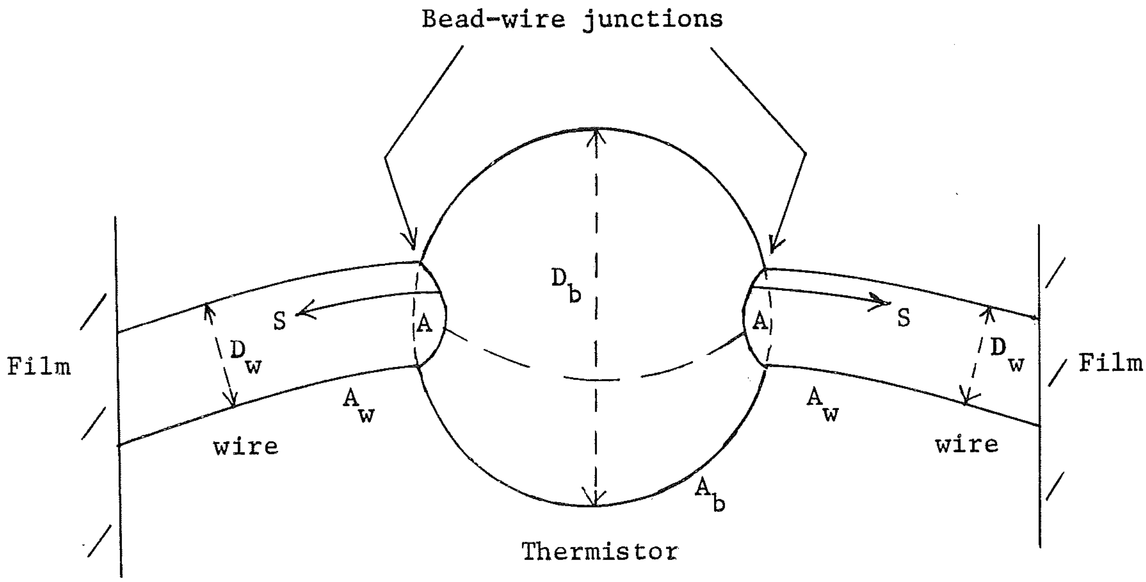


Fig. 4. Bead-wire-film system in the ARCASONDE sensor.

At the bead-wire junction, the net thermal flux has to vanish, since a planar surface has no heat capacity. Therefore, at the bead-wire junction, the heat flux out of the two wires is equal to the heat flux into the thermistor.

$$Q_c(\text{thermistor}) = 2\, Q_c(\text{wire}) \tag{25}$$

Heat conducted into the thermistor and referred to the entire surface area, A_b, can be obtained from Eqs. 24 and 25.

$$\frac{Q_c(0,\ t)}{A_b} = \frac{k_w\ D_w^2}{2D_b^2}\ \frac{\partial T_w(0,\ t)}{\partial S} \tag{26}$$

In order to evaluate the wire temperature gradient at the junction (Eq. 26), the temperature distribution in the wire must be obtained. This can be done by considering the heat fluxes along the wire, which are

1. Convective heat transfer: $h_w\left(T_r - T_w\right)$ (3)
2. Radiation: $Q_{rw} - \sigma\varepsilon_w\ T_w^4$ (22)
3. Thermal conduction: $Q_{cw}(S,\ t) = k_w\ V_w/A_w\ \partial^2 T_w(S,\ t)/\partial S^2$ (27)

The temperature change in the wire can be related to the sum of the above heat fluxes by the first law of thermodynamics, yielding the following heat transfer equation for the wire.

$$\rho_w\ \frac{C_w v_w}{A_w}\ \frac{\partial T_w}{\partial t} = h_w\left(T_{air} + \frac{r_w V^2}{2C_p} - T_w\right) + Q_{rw} - \sigma\varepsilon_w T_w^4 + k_w\ \frac{v_w}{A_w}\ \frac{\partial^2 T_w}{\partial S^2} \tag{28}$$

Equation 28 can be linearized by expanding the radiation term, $-\sigma\varepsilon_w T_w^4$, in a Taylor's series about the average wire temperature, T_{aw}.

$$-\sigma\varepsilon_w T_w^4 = 3\sigma\varepsilon_w T_{aw}^4 - 4\sigma\varepsilon_w T_{aw}^3 T_w \tag{29}$$

A solution to Eq. 28 can now be obtained by using the linearization (Eq. 24) and assuming

1. The wire temperature is steady state $\left(\partial T_w/\partial t = 0\right)$
2. The bead and film temperatures are used as boundary conditions
3. An exponential solution: $T_w(S) = A\ e^{-s\lambda_w} + B\ e^{s\lambda_w}$
   a. λ_w^{-1} is the decay length of the wire temperature distribution.

The resulting solution, as obtained by Staffanson,[17] is

$$\frac{\partial T_w(0)}{\partial S} = \lambda_w \left[\frac{T_f}{\sinh\left(\lambda_w \ell_w\right)} + T_{ew} \tanh\left(\frac{\lambda_w \ell_w}{2}\right) - T_b \coth\left(\lambda_w \ell_w\right) \right] \tag{30}$$

where

$$\lambda_w = \sqrt{\frac{h_w + 4\sigma\varepsilon_w T_{aw}^3}{k_w\ v_w/A_w}} \tag{31}$$

and

$$T_{ew} = \frac{h_w T_r + Q_{rw} + 3\sigma\varepsilon_w T_{aw}^4}{h_w + 4\sigma\varepsilon_w T_{aw}^3} \tag{32}$$

T_{ew} = the steady-state temperature of a conductively isolated wire. Thermal conduction into the thermistor can be written as a linear function of air temperature by using Eqs. 26 and 30.

$$\frac{Q_{cb}}{A_b} = \frac{k_w D_w^2 \lambda_w}{2D_b^2} \coth\left(\lambda_w \ell_w\right)\left[\frac{h_w\left(1 - \operatorname{sech}\left(\lambda_w \ell_w\right)\right)}{h_w + 4\sigma\varepsilon_w T_{aw}^3} T_{air}\right.$$

$$+ \left(1 - \operatorname{sech}\left(\lambda_w \ell_w\right)\right)\left(h_w \frac{r_w V^2}{2C_p} + Q_{rw} + 3\sigma\varepsilon_w T_{aw}^4\right)\Big/\left(h_w + 4\sigma\varepsilon_w T_{aw}^3\right) \tag{33}$$

$$\left. + T_f \operatorname{sech}\left(\lambda_w \ell_w\right) - T_b\right]$$

This equation can be abbreviated as follows:

$$\frac{Q_c}{A_b} = HK\left(K_1 T_{air} + K_2 - T_b\right) \tag{34}$$

where

$$HK = \frac{k_w D_w^2}{2D_b^2} \lambda_w \coth\left(\lambda_w \ell_w\right) \tag{35}$$

$$K_1 = \frac{h_w\left(1 - \operatorname{sech}\left(\lambda_w \ell_w\right)\right)}{h_w + 4\sigma\varepsilon_w T_{aw}^3} \tag{36}$$

$$K_2 = \left(1 - \operatorname{sech}\left(\lambda_w \ell_w\right)\right)\left(h_w \frac{r_w V^2}{2C_p} + Q_{rw} + 3\sigma\varepsilon_w T_{aw}^4\right)\Big/\left(h_w + 4\sigma\varepsilon_w T_{aw}^3\right) \tag{37}$$

$$+ T_f \operatorname{sech}\left(\lambda_w \ell_w\right)$$

All quantities in the thermal conduction Eq. 33 are known except the film temperature. This quantity will be evaluated next.

The film temperature can be obtained from the heat transfer Eq. 28 for the case of a film. It is necessary for computational purposes to approximate 28 as an ordinary differential equation by neglecting thermal conduction in the film. Mathematical simulation of the ARCAS 1A film mount in which the time dependent, two-dimensional temperature distribution is computed,[16] demonstrates that the wire-film junction temperature, T_f, is independent of heat transfer with the wire, and the film temperature is essentially uniform within three decay lengths of the junction. Heat transfer in the film can now be written as the following ordinary differential equation

$$\rho_f \frac{C_f v_f}{A_f} \frac{dT_f}{dt} = h_f\left(T_{air} + \frac{r_f V^2}{2C_p} - T_f\right) + Q_{rf} - \sigma\varepsilon_f T_f^4 \tag{38}$$

where T_f is a function of time. This equation can be approximated by the one-step finite difference equation

$$T_{fi+1} = T_{fi} + \frac{A_f \; \Delta t}{\rho_f C_f v_f} \left[h_{fi} \left(T_{air_i} + \frac{r_{fi} V^2}{2C_p} - T_{fi} \right) + Q_{rf} - \sigma \varepsilon_f T_{fi}^4 \right] \quad (39)$$

for a time interval, Δt, of about 0.5 seconds. The air temperature, T_{air}, in this equation is initially set equal to the standard air temperature, and thereafter, T_{air} is set equal to the previously calculated air temperature.

After four film temperatures are calculated, the multistep Adams-Bashforth quadature is used to complete the integration.

$$T_{fi+4} = T_{fi+3} + \frac{\Delta t}{24} \left[55 \frac{\partial T_{fi+3}}{\partial t} - 59 \frac{\partial T_{fi+2}}{\partial t} + 37 \frac{\partial T_{fi+1}}{\partial t} - 9 \frac{\partial T_{fi}}{\partial t} \right] \quad (40)$$

These integrated values of film temperature are now used in Eq. 33 to evaluate thermal conduction into the thermistor. Heat transfer by thermal conduction is one of the major sources of temperature error in the thermistor (Fig. 6e).

4. Time Constants and Decay Lengths of the Sensor

The purpose of this section is to obtain expressions for the time constant and decay length of the sensor components. These quantities have the following significance in relation to the sensor temperature.

1. The time constant, τ, is a measure of the response speed, in seconds, to a change in the sensor temperature.
2. The decay length, λ^{-1}, is a measure of distance along the sensor component through which heat transfer occurs by thermal conduction.

The expression for the time constant of the sensor can be obtained from the heat transfer equation for the thermistor bead as given in Eq. 50. An abbreviated form of this equation is

$$\tau \frac{\partial T_b}{\partial t} + T_b = T_{eb} \tag{41}$$

where the time constant is

$$\tau = \frac{\rho_b C_b V_b / A_b}{h_b + 4\sigma\varepsilon_b T_{ab}^3 + HK} \tag{42}$$

and the steady-state temperature is

$$T_{eb} = \frac{h_b\left(T_{air} + \frac{r_b V^2}{2C_p}\right) + Q_{rb} + 3\sigma\varepsilon_b T_{ab}^4 + W/A_b}{h_b + 4\sigma\varepsilon_b T_{ab}^3 + HK} \tag{43}$$

Time constants for the wire, film, and isolated bead can also be obtained from Eq. 42 with the exception that HK is equal to zero. In order to determine the effect of the time constant, τ, on the sensor temperature, a solution of Eq. 41 for T_b is obtained by assuming

1. the time constant and steady-state temperature are approximately constant in time,
2. an assumed solution is $T_b = Be^{-t/\tau} + T_{eb}$ where B is determined from the initial sensor temperature, T_{ob}.

Based on these assumptions, the time dependent solution of the sensor temperature is

$$T_b = T_{eb} + \left(T_{ob} + T_{eb}\right) e^{-t/\tau} \tag{44}$$

Thus, the time required for the sensor to obtain 95 percent of the steady-state temperature, T_{eb}, is about three time constants. During this time, the sonde has fallen through a vertical distance

$$\Delta Z = 3\tau \cdot \frac{dz}{dt} \tag{45}$$

which is the altitude resolution in measuring air temperature due to dynamic lag of the sensor temperature. If no corrections are made for dynamic lag of the sensor temperature, this altitude resolution would correspond to an error in the sensor temperature. Time constants of the bead, wire, film, and sensor, and altitude resolution are contained in the following table.

TABLE II

Time Constants and Altitude Resolution of the Sensor

Altitude (km)	Fall Speed (m/sec)	τ_b (sec)	τ_w (sec)	τ_f (sec)	τ_{sensor} (sec)	Altitude Resolution (m)
50	136.0	1.55	.02	1.89	.77	313.5
45	95.4	1.07	.01	1.84	.56	160.2
40	66.0	.79	.006	1.71	.41	81.3
35	40.2	.65	.003	1.72	.32	38.7
30	26.8	.55	.002	1.67	.27	21.6
25	16.8	.48	.001	1.51	.23	11.7

The decay length of the sensor component can be obtained from the steady-state heat transfer Eq. 28. An abbreviated form of this equation is

$$\frac{\partial^2 T}{\partial S^2} = \lambda^2 \left(T - T_e\right) \tag{46}$$

where the decay length

$$\lambda^{-1} = \sqrt{\frac{kV/A}{h + 4\sigma\varepsilon T_a^3}} \tag{47}$$

and the equilibrium temperature

$$T_e = \frac{h\left(T_{air} + \frac{rV^2}{2C_p}\right) + Q_r + 3\sigma\varepsilon T_a^4}{h + 4\sigma\varepsilon T_a^3} \tag{48}$$

In order to determine the effect of the decay length on the temperature of the sensor component, a solution of Eq. 46 is obtained by assuming

1. the decay length and equilibrium temperature are approximately constant in S
2. a solution is $T(S) = Be^{-S\lambda} + T_e$ where B is determined from the boundary condition.

Based on these assumptions, the distribution of the sensor temperature is

$$T(S) = T_e + \left(T_o - T_e\right)e^{-S\lambda} \tag{49}$$

where T_o = the sensor temperature at S = 0. The decay length, λ^{-1}, is a measure of the effective conduction length of the sensor component, in particular, a point ten decay lengths or greater away from a source is insulated from that source. Therefore, if both the thermistor and film are separated by ten lengths of wire, the thermistor is assumed to be insulated from the film. Film properties within about three decay lengths of the wire-film junction, except for strong sources, essentially determine the temperature of the junction. Thus, the convection coefficient, h, based on three decay lengths of film represents the

the effective h for the wire-film junction near the leading edge of the film.

Based on rocketsonde data, the thermistor remains decreasingly influenced by the film down to 25 kilometers, but becomes strongly dependent on the film above 45 kilometers. A list of decay lengths for the wire and film along with the wire length in terms of its decay lengths is given in the following table.

TABLE III

Decay Lengths of the Wire and Film (mm)

Altitude (km)	λ^{-1} Wire	λ^{-1} Film	ℓ_w/λ^{-1} Wire
50	1.4	9.3	2.3
45	1.1	8.3	2.9
40	.8	8.1	4.0
35	.6	8.0	5.3
30	.5	7.8	6.4
25	.4	7.5	8.0

Above 25 kilometers, the thermistor and film are well within three decay lengths of the wire. Above 45 kilometers, the decay length of the wire temperature is less than the characteristic length of the wire, which implies very strong thermal conduction between the thermistor and film.

III. RESULTS OF ROCKETSONDE MEASUREMENTS

1. Air Temperature

The major objective of this chapter is to present results of applying the program to obtain the air temperature from the sensor temperature. The temperature of the sensor is determined from the following heat sources into the thermistor:

1. Thermal conduction $HK\left(T_k - T_b\right)$ where $T_k \equiv$ conduction temperature of the atmosphere.
2. Convection heat exchange $h_b\left(T_r - T_b\right)$ where T_r = recovery temperature.
3. Radiation heating $Q_{rb} - \sigma\varepsilon_b T_b^4$, Q_{rb} = radiation input to the thermistor.
4. Electric heating = W/A_b which is assumed to be equal to about 20 W/m^2.

Relating the change in thermistor temperature to the sum of the above heat sources yields the following heat transfer equation:

$$\frac{(\rho Cv)_b}{A_b}\frac{\partial T_b}{\partial t} = h_b\left(T_r - T_b\right) + HK\left(T_k - T_b\right) + Q_{rb} - \sigma\varepsilon_b T_b^4 + \frac{W}{A_b}\left[W/m^2\right] \qquad (50)$$

The solution of Eq. 50 for air temperature can be written as a sum of the sensor temperature plus terms corresponding to heat sources to the thermistor bead.

$$
\begin{aligned}
T_{air} = {} & T_b && \text{sensor temperature} \\
& + \left(HK\left(1 - K_1\right)T_b - K_2\right) \Big/ \left(h_b + HK \cdot K_1\right) && \text{conduction temperature correction} \\
& - \frac{h_b r_b V^2}{2C_p} \Big/ \left(h_b + HK \cdot K_1\right) && \text{aerodynamic temperature correction} \\
& + \frac{(\rho Cv)_b}{A_b} \frac{\partial T_b}{\partial t} \Big/ \left(h_b + HK \cdot K_1\right) && \text{dynamic lag temperature correction} \\
& + \left(\sigma \epsilon_b T_b^4 - Q_{rb}\right) \Big/ \left(h_b + HK \cdot K_1\right) && \text{radiation temperature correction} \\
& - \frac{W}{A_b} \Big/ \left(h_b + HK \cdot K_1\right) && \text{electric temperature correction}
\end{aligned}
\tag{51}
$$

Although these terms are so named, each is influenced by all the heat sources. A graph of the air temperature as a function of altitude along with the sensor and standard air temperature is contained in Fig. 5. The air temperature, as contained in Fig. 5, deviates by more than one degree Kelvin from the sensor temperature above 40 kilometers. Note also that the external heat sources (discussed previously in this paper) have increased the sensor temperature beyond that of the air and standard temperatures. Thus, the sensor temperature must be corrected for these heat sources in order to yield the correct air temperature. Small fluctuations of the calculated air temperature below 30

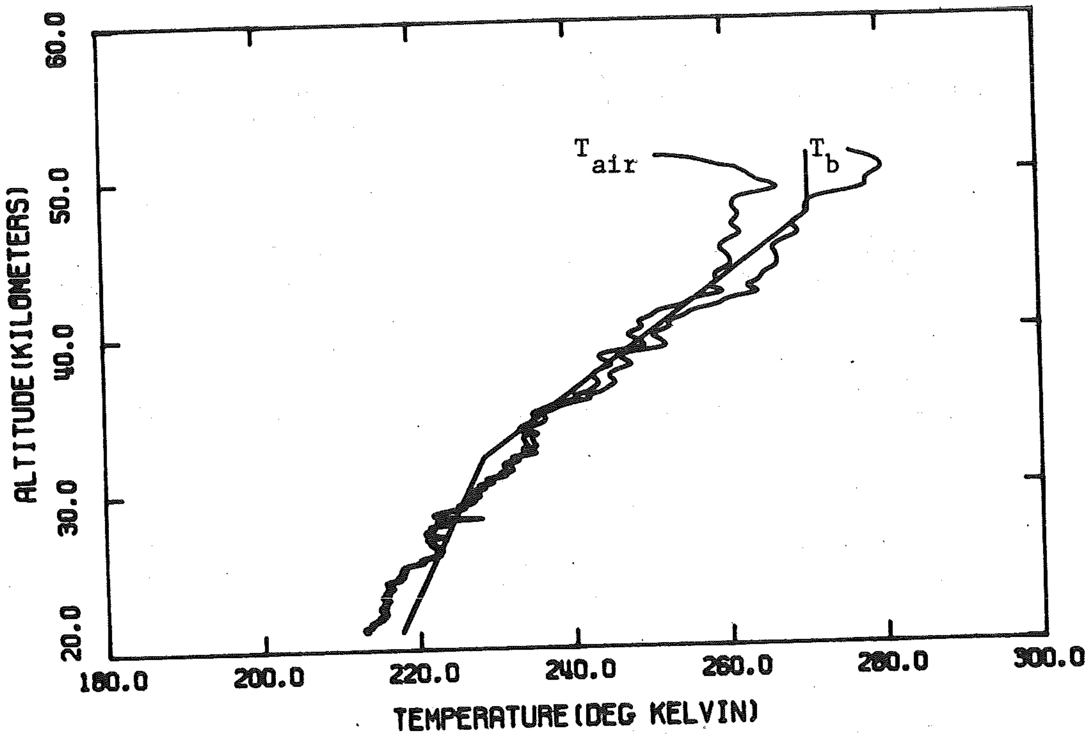


Fig. 5. Standard, sensor, and air temperature profiles.

kilometers, where temperature corrections are negligible, must be the result of the atmosphere if telemetry errors have been corrected. Thus, the detailed air temperature fluctuations above 30 kilometers, where sensor temperature corrections are larger, must also be due to the atmosphere. The air temperature lapse rate below 50 kilometers is less than about 8°K/km.

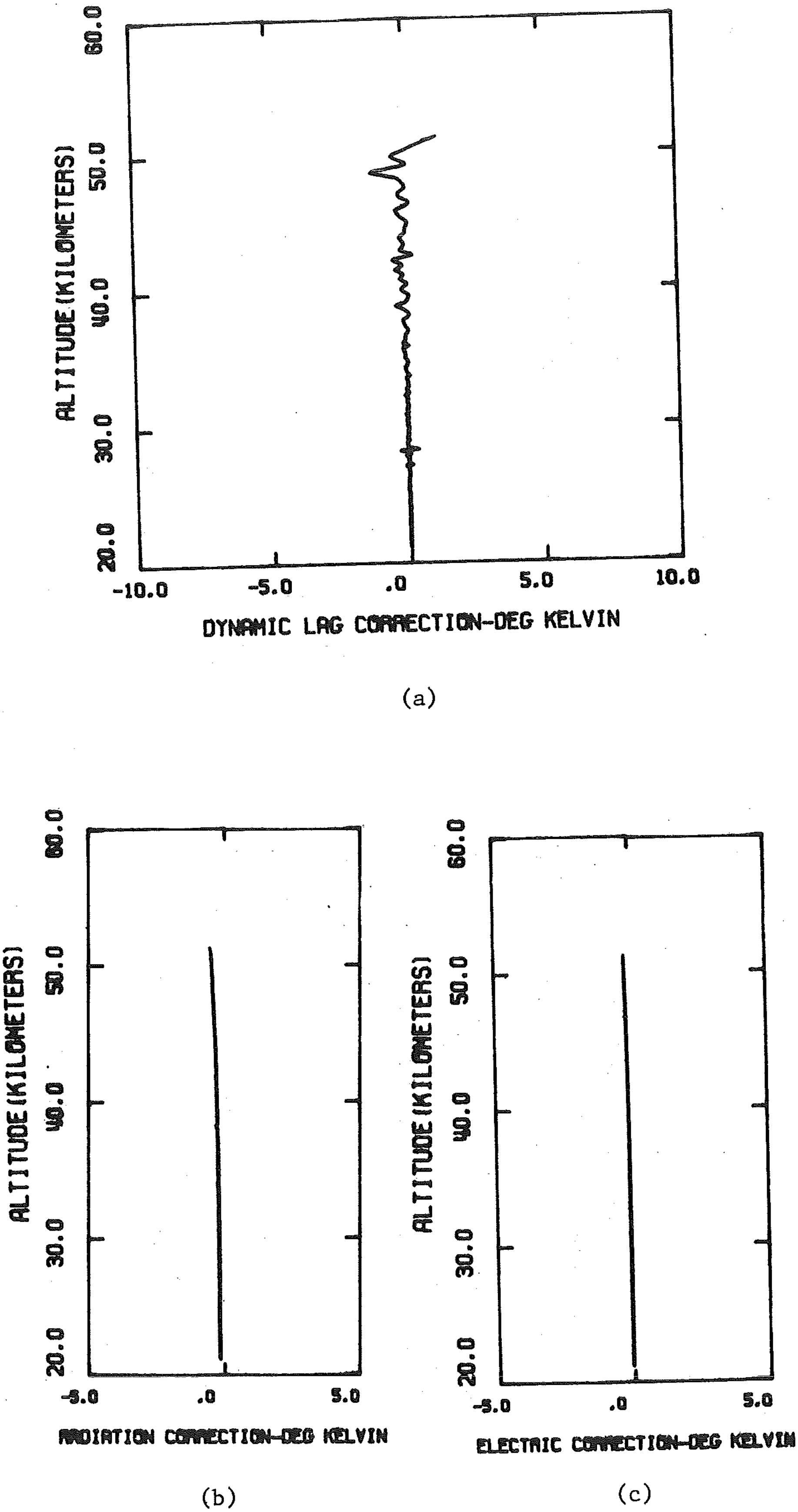
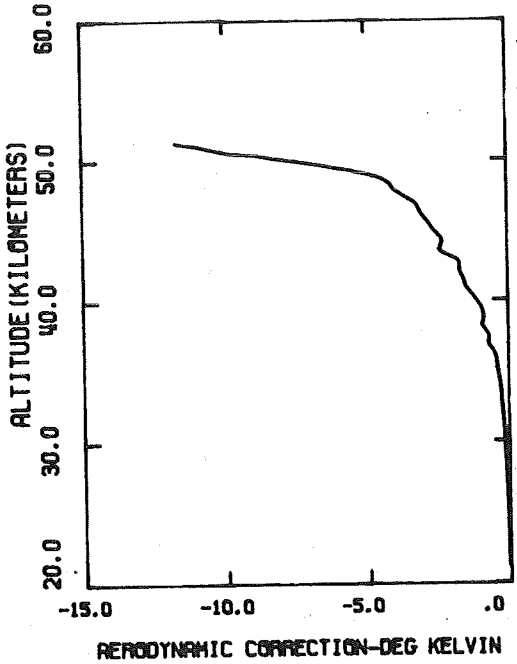
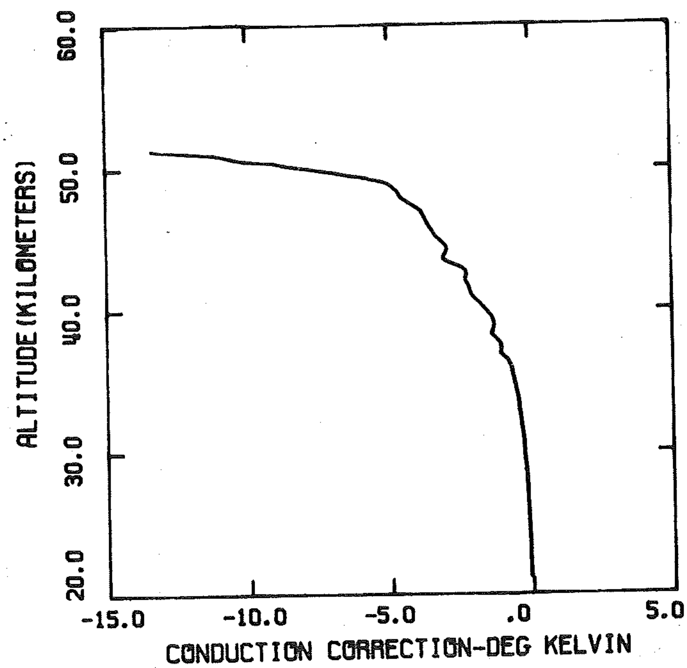


Fig. 6. Temperature corrections.



(d)



(e)

Fig. 6 (continued). Temperature corrections.

Graphs of the sensor temperature corrections as a function of altitude are contained in Figs. 6a to 6e. As shown in Figs. 6a to 6e, the temperature corrections due to radiation and electrical heating are negligible at altitudes below 50 kilometers. The temperature errors due to thermal conduction and aerodynamic heating are significantly large above 30 kilometers. For example, at 50 kilometers, these heat sources result in an increase in the sensor temperature of about 20°K. Note also that both of these curves have the same shape as the fall speed of the rocketsonde. Thus, a decrease in the air speed of the rocketsonde (particularly at high altitudes) by using a disk-gap-band parachute (as compared to a hemispherical parachute) would reduce errors due to thermal conduction and aerodynamic heating.

2. Horizontal Winds

The horizontal winds for a rocketsonde flight can be obtained from radar data and the equation of motion for the rocketsonde-parachute system. The forces acting on the falling system are assumed to be gravity and drag. The resultant force yields the following acceleration:

$$\frac{d^2\vec{r}}{dt^2} = -g(z)\vec{k} + \vec{\vec{DF}} \left[m/sec^2\right] \tag{52}$$

Gravity can be expressed as a function of altitude by the formula

$$g(z) = g(o)\left[1 - \frac{2z}{R_e} + \frac{3z^2}{R_e^2}\right] \tag{53}$$

where R_e is the mean radius of the earth. The drag force per unit mass obtained from dimensional analysis is

$$\vec{\vec{DF}} = \frac{\rho v}{2m} C_D A |V_R| \vec{V}_R \tag{54}$$

where

C_D = nondimensional drag coefficient

A = parachute

V_R = air speed of the sonde .

The position of the sonde with respect to the ground station is shown in the following figure.

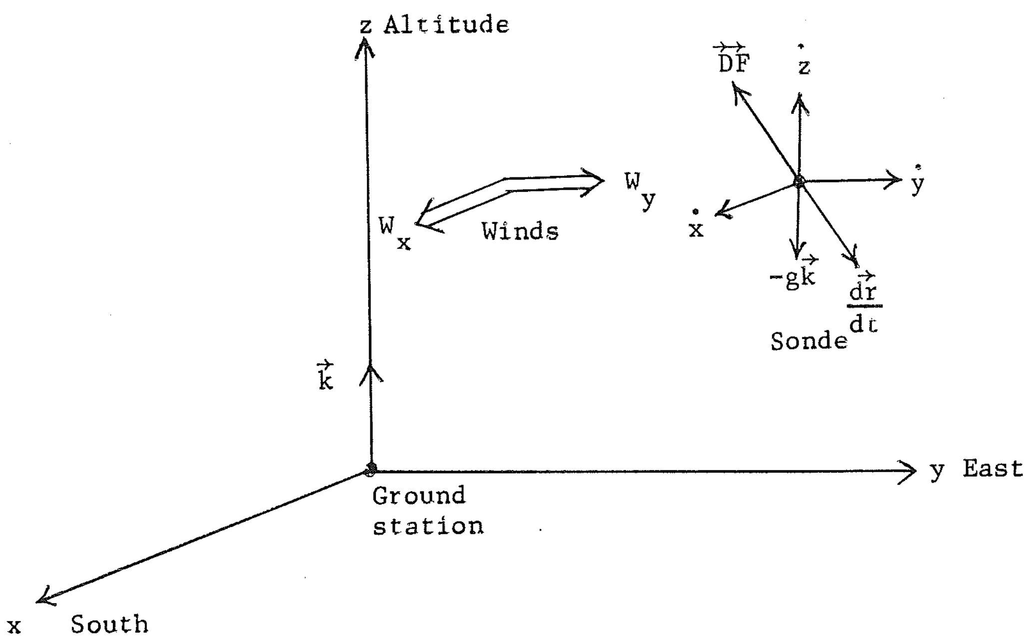


Fig. 7. Forces acting on a descending rocketsonde.

Neglecting earth rotation, the equation of motion for the sonde-parachute system can be written as

East component: $$d^2y/dt^2 = +K\left(\frac{dy}{dt} - W_y\right) \tag{55.a}$$

South component: $$d^2x/dt^2 = +K\left(\frac{dx}{dt} - W_x\right) \tag{55.b}$$

Vertical component: $$d^2z/dt^2 = -g + K\left(\frac{dz}{dt} - W_z\right) \tag{55.c}$$

where K is defined as $\frac{\rho v}{2m} C_D A|V_R|$. These three equations can be solved for the horizontal winds $\left(W_x, W_y\right)$, and K, assuming the vertical wind, W_z, is zero.

$$K = +\left(d^2z/dt^2 + g\right)\Big/dz/dt \tag{56.a}$$

$$W_x = -\left(d^2x/dt^2\right)\Big/k + dx/dt \tag{56.b}$$

$$W_y = -\left(d^2y/dt^2\right)\Big/k + dy/dt \tag{56.c}$$

Values of the first and second derivatives of position with respect to time can be evaluated and are obtained from the subroutine DIRSIT using radar data. Substituting Eq. 56 into the equation for air speed yields

$$|V_R| = \sqrt{\left(\frac{dx}{dt} - W_x\right)^2 + \left(\frac{dy}{dt} - W_y\right)^2 + \left(\frac{dz}{dt}\right)^2} \tag{57}$$

and the total drag force on the parachute

$$DF = K|V_R| \tag{58}$$

A graph of the horizontal winds as a function of altitude is contained in Fig. 8.

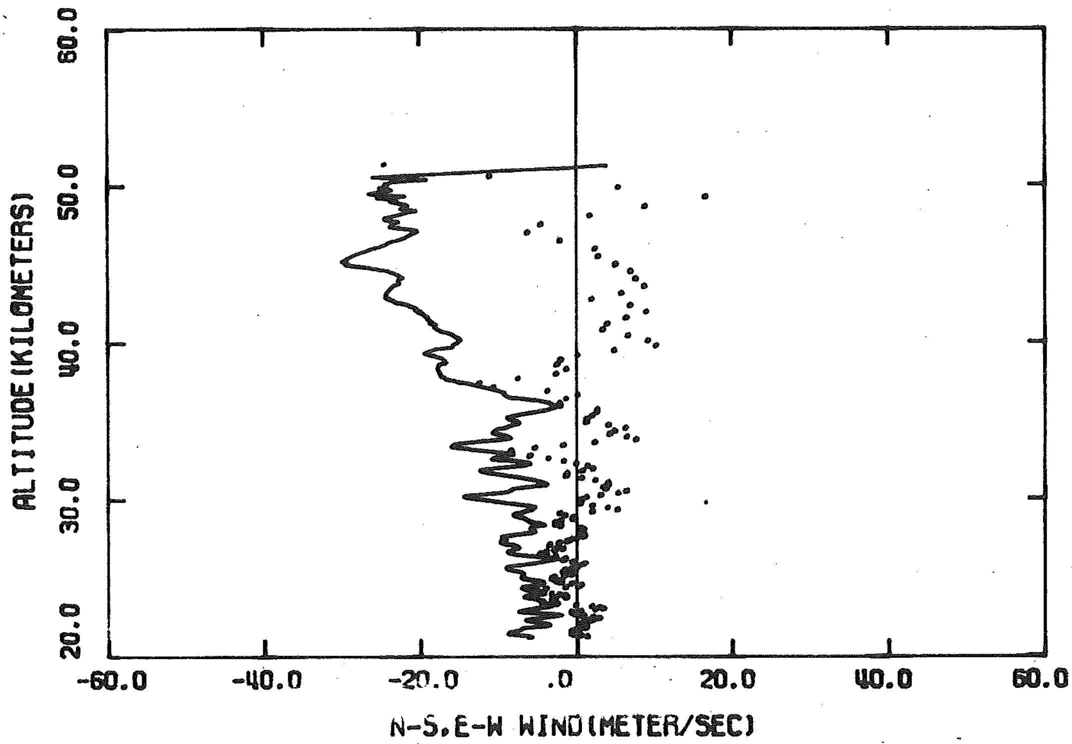


Fig. 8. Horizontal winds.

As seen from Fig. 8, the solid curve representing the eastward zonal wind is much larger than the meridional south wind. A maximum wind speed of about 30 m/s occurs in the region of 45 kilometers, suggesting the existence of a stratopause jet stream at this altitude.[11] Since the wind is approximately geostrophic at rocketsonde altitudes, the horizontal pressure gradiant, $\nabla_H p$, can be determined from the geostrophic wind equation[10]

$$W \approx \frac{1}{(2\Omega \cos \zeta)\rho} \nabla_H p \tag{59}$$

As an example, at 45 kilometers and 40 degrees latitude

$$\rho\,(\text{air}) \approx .2 \cdot 10^{-2}\ \text{kg/m}^3$$

$$W(\text{horizontal wind}) \approx 30\ \text{m/sec}$$

$$2\Omega \cos \zeta \approx .5 \cdot 10^{-4}\ \text{rad/s}$$

Thus, the geostrophic approximation of the horizontal pressure gradiant at 45 kilometers is

$$\nabla_H p \approx 3 \cdot 10^{-6}\ \text{N/m}^3$$

3. Pressure and Density Calculations

Atmospheric pressure and density can be calculated as a function of altitude from the air temperature profile, as contained in Eq. 51, and a reference value obtained from radiosonde data. Pressure at an altitude Z_{i+1} is obtained by using the hydrostatic equation and the ideal gas law and integrating over an altitude interval from Z_i to Z_{i+1}.

$$p_{i+1} = p_i \; \mathrm{EXP} \left\{ -\frac{1}{R_D} \int_{Z_i}^{Z_{i+1}} \frac{g(z)}{T_{air}} \, dZ \right\} \left[\frac{N}{m^2} \right] \tag{60}$$

where

$$R_D = \text{gas constant for dry air} \left[\frac{J}{kg\,°K} \right]$$

The first pressure in this integration is obtained by linearly interpolating into the radiosonde data at the lowest rocketsonde altitude, since radiosonde data is more reliable at the lower altitudes. Additional pressures are obtained from the following numerical scheme:

1. Two Lagrange polynomials are fitted to the function g/T_{air} (using rocketsonde data) at the altitudes Z_{i-1}, Z_i, Z_{i+1} and Z_i, Z_{i+1}, Z_{i+2}.
   a. The coefficients of these polynomials are a_i, b_i, c_i.
2. These two polynomials are averaged together and integrated upward between the altitudes Z_i and Z_{i+1} yielding the following pressure, p_{i+1}:

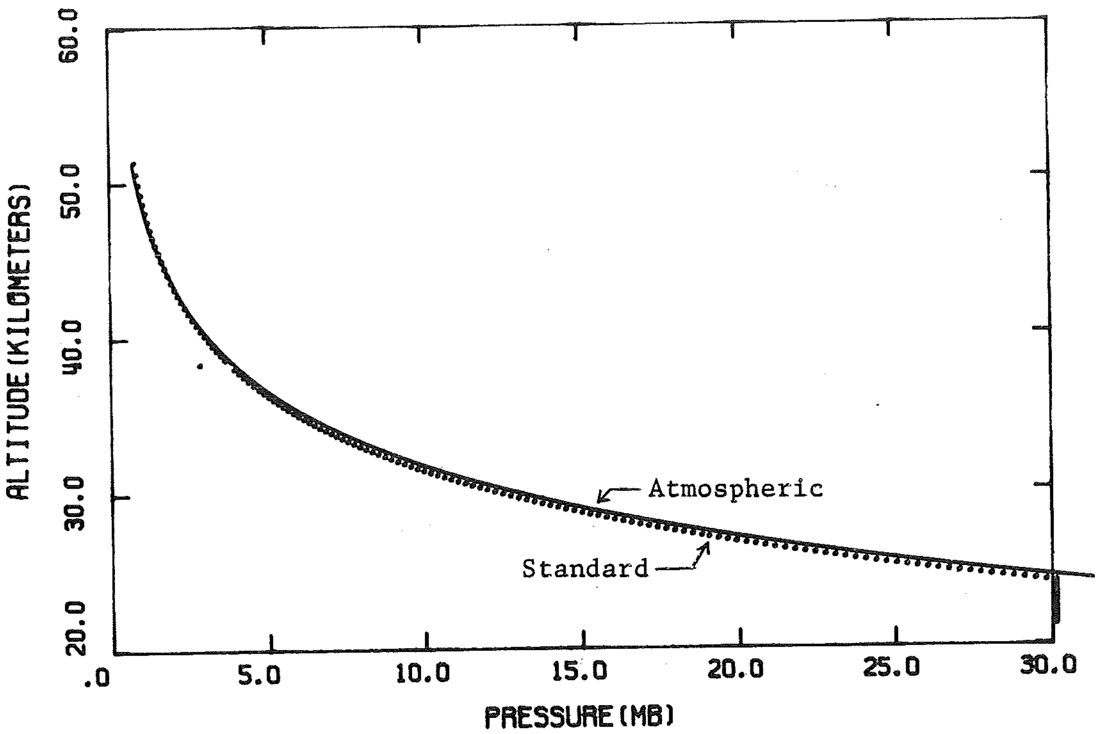


Fig. 9. Atmospheric and standard pressure profile.

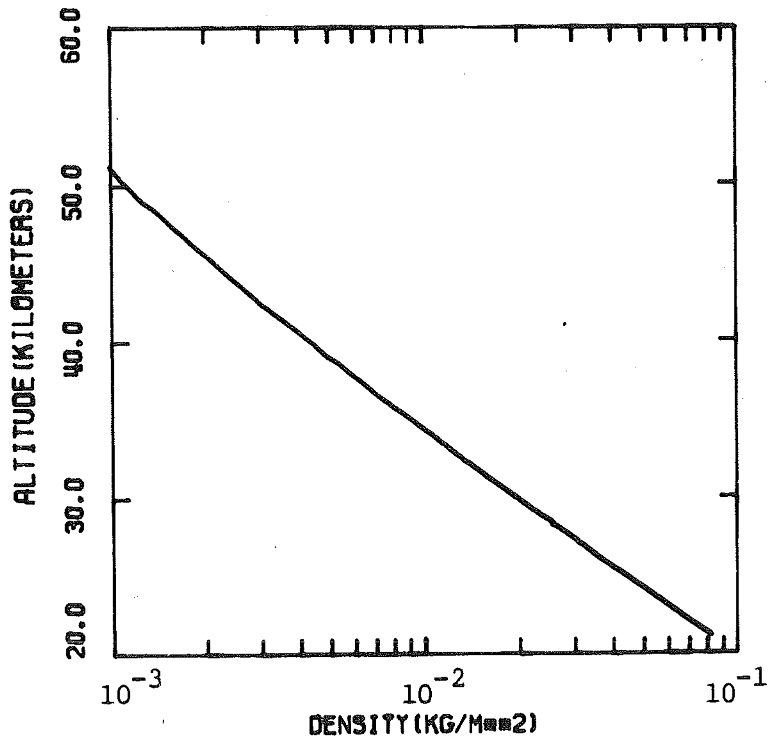


Fig. 10. Atmospheric density.

$$p_{i+1} = p_i \text{ EXP} \left[- \frac{1}{R_D} \left\{ \frac{a_i + a_{i+1}}{2} \cdot \frac{Z_{i+1}^3 - Z_i^3}{3} \right. \right. \tag{61}$$

$$\left. \left. + \frac{b_i + b_{i+1}}{2} \cdot \frac{Z_{i+1}^2 - Z_i^2}{2} + \frac{c_i + c_{i+1}}{2} \cdot \left(Z_{i+1} - Z_i \right) \right\} \right]$$

The air density can be obtained from the pressure (Eq. 61) and air temperature as follows:

$$\rho_i = \frac{p_i}{R_D \, T_{air_i}} \tag{62}$$

Figures 9 and 10 illustrate the results of calculating the air pressure and density based on atmospheric temperature. Note that the computed values of the atmospheric pressure and density are greater than the standard atmosphere values as given in the U.S. Standard Atmosphere Tables, 1962[24] and Fig. 8. Knowing the temperature, pressure, and density of the air, one can compute the following atmospheric parameters:

1. thermal conductivity J/(ms°K)
2. viscosity m^2/s
3. mean free path m
4. speed of sound m/s

Formulas for the above quantities are contained in the U.S. Standard Atmosphere, 1962.[24]

$$k = \frac{6.325 \cdot 10^{-7}\, T_{air}^{3/2}}{\left(T_{air} + 245.4 \cdot 10^{-12/T_{air}}\right) 4186.0465} \tag{63}$$

$$\mu = \frac{1.458 \cdot 10^{-6}\, T_{air}^{3/2}}{T_{air} + 110.4} \tag{64}$$

$$L = \frac{R_D\, T_{air} \cdot 10^{+3}}{\sqrt{2}\, \pi\, 6.02257 \cdot 10^{26} \left(3.65 \cdot 10^{-10}\right)^2 p} \tag{65}$$

$$C_S = \sqrt{1.4\, R_D\, T_{air}} \tag{66}$$

These parameters can be used to calculate the convection coefficients and recovery factors of the bead-wire-film temperature sensor. Computational results for the mean free path and speed of sound are contained in Table IV.

4. Conclusions and Summary

The complete problem of obtaining temperature, pressure, and density of the atmosphere and horizontal winds from a rocketsonde flight is described in the flow chart of Fig. 11. The subject of this paper has been concerned only with describing the mathematical model for the data reduction problem enclosed by the dashed line. The most important assumptions which have been made to obtain this mathematical model are the following:

1. The bead, wire, and film are the components of the ARCASONDE temperature sensor.
2. There is no thermal conduction in the film.
3. Heat flux from the wires does not effect the film temperature distribution.
4. The temperature of the wire-film junction is equal to the uniform film temperature distribution.
5. The wire responds instantaneously to temperature changes.
6. Temperature errors in the thermistor are due to
   a. thermal conduction
   b. aerodynamic heating
   c. dynamic lag
   d. electric and radio frequency heating
   e radiation.
7. Nominal values for the physical sensor parameters can be obtained from references (Appendix C).
8. The ideal gas law and the hydrostatic equation are valid.

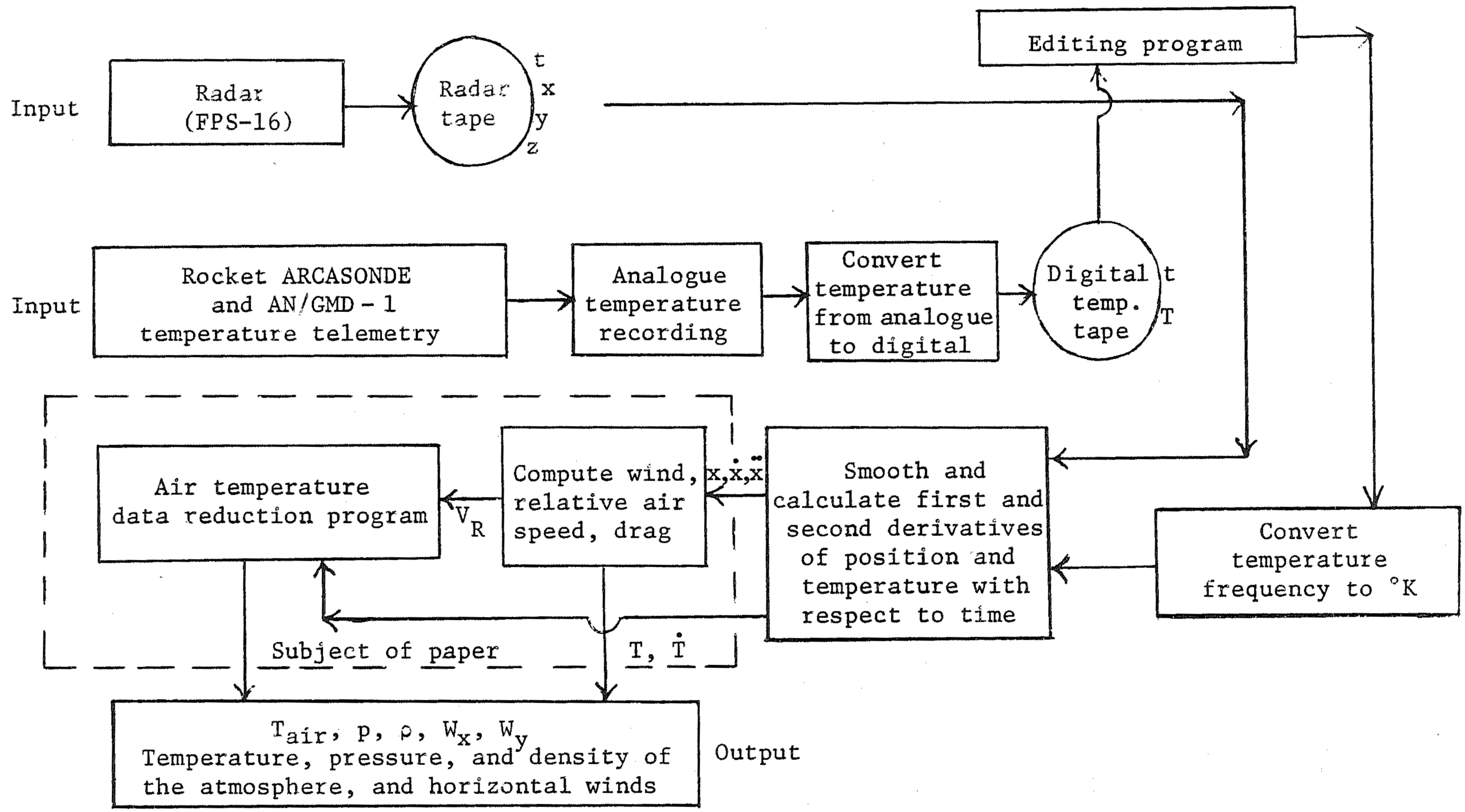


Fig. 11. System flow chart for rocketsonde measurements.

The results of the formulas developed in this chapter for calculating atmospheric parameters are listed in Table IV at 1000 meter intervals. In addition, radiosonde information from the Meteorological Rocket Network publication is included for comparison with the overlapping rocketsonde data. The following comparisons can be made between the radiosonde and rocketsonde data (in the overlapping region):

1. Air pressure is essentially the same in both cases.
2. The radiosonde temperature is higher than the rocketsonde temperature.
3. The wind in both cases follow the same pattern. The variance may be due to an averaging process applied to the radiosonde data which was not applied to rocketsonde data.

Note that the difference between the calculated air and the rocketsonde temperatures are large at high altitudes where the air speed is high. In addition, the mean free path of the atmosphere, L, is larger than the characteristic length of the wire above 42 kilometers, while this is never true for the thermistor and film.

A flow chart of the air temperature data reduction program, which has been the major emphasis of this paper, is illustrated in Fig. 12. Note that the quantities which directly determine the sensor temperature corrections are

1. the convection coefficient and recovery factor of the thermistor: h_b, r_b
2. thermal conduction parameters: HK, K_1, K_2
3. radiation and electric heating of the thermistor: W, Q_{rb}

TABLE IV

ROCKETSONDE AND RADIOSONDE DATA

Rocketsonde data										Radiosonde data				
dZ/dt m/s	Z kilometer	W_x m/s	W_y m/s	P mb	$\rho \cdot 10^{-2}$ kg/m^3	C_S m/s	$L \cdot 10^{-4}$ m	T_b °K	T_{air} °K	Z km	T_{air} °K	W_x m/s	W_y m/s	P mb
-152.0	51	-20.93	4.67	.74	.101	320.8	.80	277.7	255.2					
-136.0	50	1.03	-24.96	.84	.112	325.1	.72	280.0	262.8					
-118.06	49	11.63	-23.72	.96	.125	327.2	.64	277.8	266.5					
-114.10	48	1.25	-23.50	1.08	.145	323.8	.56	270.6	260.9					
-105.23	47	-6.27	-20.21	1.23	.164	324.0	.49	269.5	261.3					
-100.62	46	1.47	-25.81	1.41	.187	324.2	.43	269.1	261.6					
-95.31	45	4.20	-29.19	1.60	.214	323.0	.38	266.1	259.6					
-91.27	44	7.15	-22.65	1.82	.243	323.4	.33	266.4	260.2					
-83.08	43	4.00	-24.31	2.07	.279	322.3	.29	263.7	258.5					
-78.89	42	8.17	-19.84	2.37	.322	320.4	.25	260.4	255.5					
-75.20	41	3.01	-18.10	2.70	.376	317.1	.22	254.6	250.3					
-65.68	40	9.09	-15.19	3.09	.434	315.7	.19	251.3	247.9					
-58.96	39	-1.15	-17.21	3.53	.494	316.3	.16	251.8	249.0					
-58.53	38	-2.64	-17.37	4.06	.578	313.8	.14	247.6	245.1					
-53.65	37	-9.81	-10.71	4.65	.667	312.6	.12	245.2	243.1					
-43.43	36	-2.84	-2.87	5.36	.777	310.8	.10	242.0	240.4					
-40.14	35	.66	-7.85	6.18	.915	307.6	.089	236.9	235.4					
-36.38	34	5.11	-8.80	7.13	1.065	306.2	.076	234.6	233.4					
-34.25	33	-9.45	-9.93	8.25	1.229	306.6	.066	235.1	234.0					
-31.49	32	1.44	-10.03	9.51	1.428	305.5	.057	233.1	232.2	32	234.6	1.	-9.	9.5
-28.43	31	3.56	-4.08	10.99	1.661	304.4	.049	231.4	230.6					
-26.80	30	.45	-12.97	12.76	1.958	302.0	.041	227.8	227.0	30	231.0	1.	-7.	12.7
-24.07	29	-2.63	-8.16	14.83	2.294	300.8	.035	225.8	225.1					
-21.80	28	.39	-5.35	17.23	2.695	299.3	.030	223.4	222.9	28	227.1	0.	-6.	17.0
-20.47	27	-4.16	-7.85	20.03	3.150	298.3	.026	222.1	221.5					
-19.17	26	-1.61	-4.45	23.37	3.662	298.9	.022	222.8	222.3	26	223.1	-1.	-9.	23.0
-16.76	25	-3.17	-7.07	27.23	4.355	295.9	.019	218.4	217.9					
-15.41	24	-4.61	-4.10	31.86	5.142	294.5	.016	216.3	215.9	24	219.2	-2.	-6.	31.2
-13.95	23	2.76	-5.64	37.26	6.025	294.2	.013	215.8	215.4					
-13.51	22	.21	-3.57	43.63	7.075	293.8	.011	215.2	214.8	22	216.7	-1.	-3.	42.5
										20	215.2	0.	2.	58.0

4. physical parameters of the thermistor (Appendix C)

5. sensor temperature and its first derivative with respect to time: T_b, dT_b/dt

6. the relative air speed of the rocketsonde: V_R

Properties of the wire and film are used to compute the thermal conduction parameters which directly influence the sensor temperature corrections. The characteristic length of the film, CLF, is computed to be within 10^{-3} meters of three decay lengths of the film.

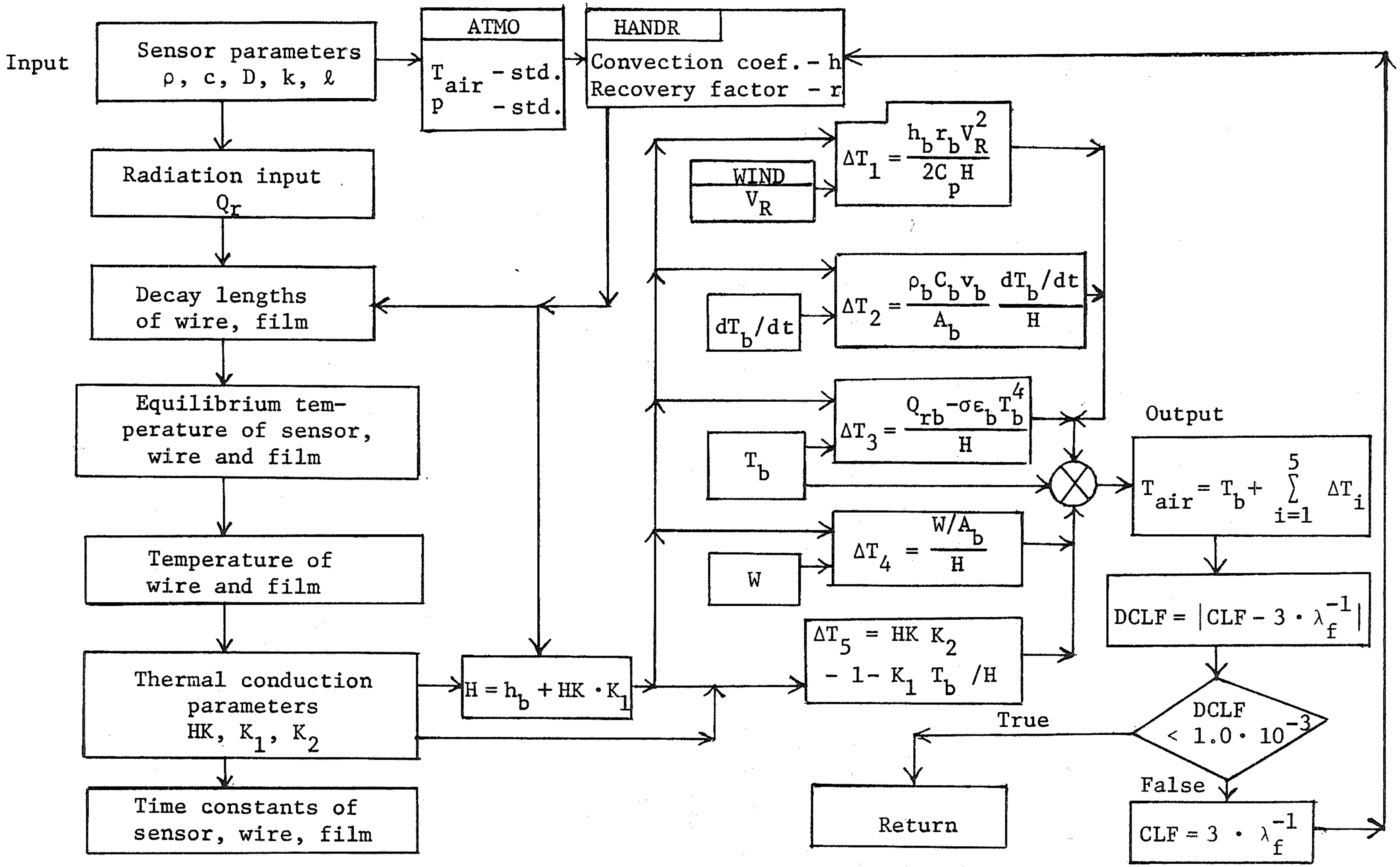


Fig. 12. Air temperature reduction flow chart.

APPENDIX A

COMPUTER PROGRAM

A computer program written in FORTRAN IV has been designed for the UNIVAC 1108 to compute temperature, density, and pressure of the atmosphere and horizontal winds from the ARCASONDE temperature sensor and its radar track. This program uses digital radar and temperature tapes from rocketsonde measurements as input. Initially, records of the radar and temperature tape are skipped in order to establish an approximate coinciding point in time for both sonde position and sensor temperature. Then, all the reference frequency and a beginning portion of the frequency data for the sensor are read. A least squares fit is applied to the reference frequency. One record of radar tape is read and groups of five points are averaged together. The third point is taken as the time for the averaged group. If the radar time is out of range of the temperature data, another record of the temperature tape is read. This time is linearly interpolated into the frequency data. The resulting frequency value is divided by the corresponding reference frequency to obtain the frequency ratio of the rocketsonde. The frequency ratio is then linearly interpolated into the calibration curve to obtain sensor temperature in degrees Kelvin.

At this point, the program is ready to accept time, sensor temperature, and radar data to compute air temperature, pressure, density, and horizontal winds. The complete data reduction program consists of twelve subroutines. The main data correction subroutine, FSCINV, applies corrections to the sensor temperature to obtain air temperature. A statement description of the asterisked subroutines is included in this appendix. The other subroutines, such as HANDR, will be included in future reports. The amount of core storage, in octal notation, is also estimated for each subroutine.

Subroutine	Core Storage Length (octal)
* MAIN	12244
* DRIVER	47013
* GRAF	1005
ATAIAT	711
* RATIO	2114
* ATMO	1375
* FSCINV	2262
* WIND	304
INITAL	1012
DIRSIT	2205
HANDR	2172
* INTEG	431
Total	77537

The purpose of each subroutine and its relationship to the other subroutines is illustrated by the flow chart in Fig. 13.

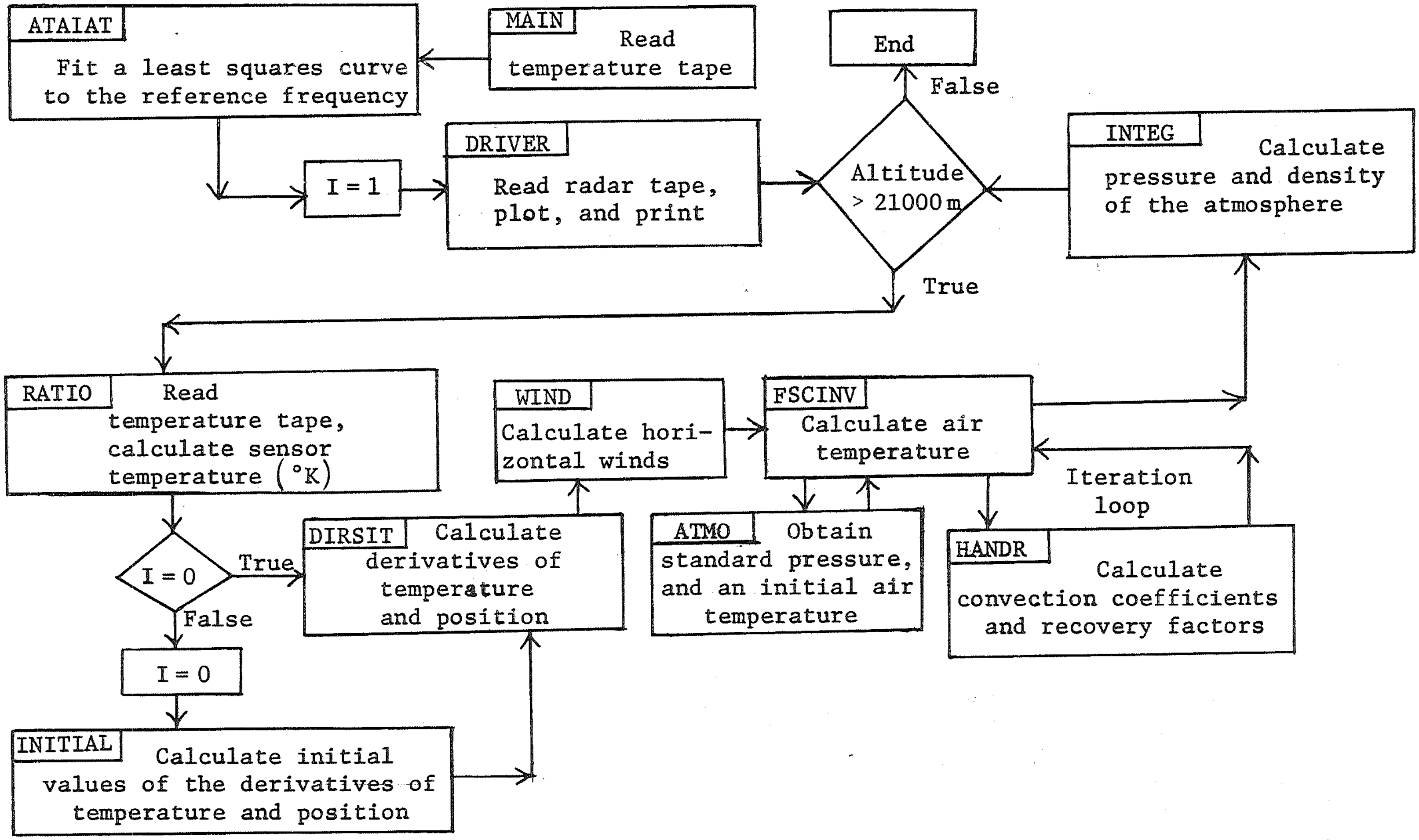


Fig. 13. Flow chart of the computer program.

MAIN PROGRAM

The main program reads in all of the reference temperature and a beginning portion of the sensor temperature.

Statement	Variable	Description
1	S	Storage array for one record of temperature tape.
2	WA, WP	Radiosonde altitude and pressure.
3	Y, X	Sensor temperature and time.
4	YL, XL	Reference temperature and time.
7	FRT, TMP	Calibration frequency ratio and sensor temperature (°C).
	FMRK1, FMRK2	Minimum and maximum calibration frequency ratio.
8	BS, CS	Coefficients of the linear equation for standard temperature.
	PO, AS	Standard pressure versus altitude.
9	XLAT, XLONG	Latitude and longitude of the station.

Statement	Description
11	Skip two records or 72 seconds of temperature tape.
12	Skip 15 records or 240 seconds of radar tape.
14-21	Read on punched cards: a. standard atmospheric pressure b. calibration curve c. standard temperature coefficients d. latitude and longitude e. radiosonde pressure

Statement	Description
36	Read in one record of temperature tape.
38	If the frequency is less than 10.0 ignore.
39	If IR = 0, store time in QZ.
40	If the frequency is greater than 165.0, go to statement 45.
41	Subtract 12 seconds from the time and store in X.
42	Store sensor frequency in Y.
43	II = number of sensor frequencies.
47	Store the sum of reference frequencies in SUM.
48	If the time increment is greater than 0.5 seconds, continue.
49	If there are less than 40 reference frequencies, ignore.
50	NP = number of reference frequencies.
53	YL = average reference frequency.
54	XL = average of the first and last reference time.
63	Print out reference frequency and time.
65	Call ATAIAT to fit a least squares curve to the reference frequency.
66	Call DRIVER subroutine.
70	END

DRIVER SUBROUTINE

The DRIVER subroutine handles the mechanics of data reduction in the following order:

a. sensor parameters and radiation inputs are read in

b. the radar tape is read

c. five positions from the radar tape are averaged together

d. the data reductions subroutines are called

e. variables are stored and plotted in blocks of 500 words.

Statement	Variable	Description
2	Z	Storage array for one record of radar tape.
3-6	HEAD1-HEAD18	Storage arrays for plotting annotation.
7-8		Storage arrays for plotting.
9	Z1, Z2	Pressure and density of the atmosphere.
11	P	Standard air pressure.
12	STAIR	Standard air temperature.
13	T	Time - s.
	X	Position - m.
	XBAR	Average position - m.
	XDOT	First derivative of position - m/s.
	XDDOT	Second derivative of position - m/s^2.
14		Indexes used in DIRSIT.
15	TEMT	Sensor temperature - °K.
	TEDOT	First derivative of sensor temperature with respect to time - °K/s.
	ZMARK	5000 meter printout index.
	DTIME	Time increment for integration in the FSCINV subroutine.
	LRUN	Index for label printout in DRIVER.
16		Standard atmosphere temperature and pressure.
18-19	TOO	Time - s.
	XR, YR, ZR	Raw position - m.
	XS, YX, ZS	Smooth position - m.
	XD, YD, ZD	First derivative of the smooth position - m/s.

Statement	Variable	Description
	XDD, YDD, ZDD	Second derivative of the smooth position - m/s^2.
	TE	Sensor temperature - °K.
	TD	First derivative of sensor temperature - °K/s.
	TDD	Second derivative of sensor temperature - $°K/s^2$.
21	CLB	Characteristic length of the thermistor bead - m.
	CLW	Characteristic length of the wire - m.
	CLF	Characteristic length of the film - m.
	CLFILM	Length of film along the air flow - m.
23	ZOT	Altitude - m.
	RHO	Atmospheric density - kg/m^3.
	VS	Speed of sound - m/s.
	AMU	Atmospheric viscosity - kg/(m s).
	AK	Thermal conductivity of the atmosphere - W/(m°K).
	AMFP	Mean free path of the atmosphere - m.
	RTV	Relative air speed of the sensor - m/s.
	TPINF	Air temperature - °K.
24	TOTRAD	Total radiation flux density.
25	EPS	Emissivity of the sensor.
	RHOC	Density - kg/m^3 times the specific heat - J/(kg°K) of the sensor.
	D	Diameter of the sensor component - m.
	W	Electric heating of the thermistor - W/m^2.
	ZKD	Conductivity - W/(m°K) times the diameter - m of the sensor component.
26	S	Width of the film strip - m.
	SMB	Length of the inner film strip - m.
	ZLL	Length of the outer film strip - m.
	ZL	Length of the wire - m.
	XEDGE	Length of the leading edge of the film strip - m.

Statement	Description
27-31	Format statements for reading.
35-46	Read in the sensor parameters and radiation inputs.

Statement	Description
35-46	Read in the label annotation for plotting.
67-100	Print out sensor parameters and radiation input.
102	AMASS = mass of rocket-parachute system.
103	AREA = cross sectional area of parachute.
113	Set the characteristic length of the film equal to CLFILM.
118	Read one record of radar tape.
119	Begin the DO loop for the radar data.
122-124	Summing variables.
127	Begin DO loop to average five radar positions together.
129	Average time is at the third position.
132	Using the average time, TIM, call RATIO to obtain the sensor temperature, TEMPT.
134-136	Add the five radar positions together.
138-140	Calculate the following average positions: X(I, 1) South X(I, 2) East X(I, 3) Altitude.
143-145	Calculate ZMARK, the 5000 m. interval printout index.
150	Call INITAL subroutine to obtain initial values of the first and second derivatives of temperature and position.
156	Set the maximum plot size.
161	Begin the data reduction cycle.
163	Read one record of radar tape.
164	If there is no radar data, go to statement 393 and rewind the tapes.
171	Call DIRSIT to obtain first and second derivatives.

Statement	Description
175	Calculate the time increment, DTIME.
177-179	Heading print out.
182	Call WIND subroutine to obtain horizontal winds, relative air speed, gravity, and drag.
184	Call FSCINV to obtain air temperature and corrections.
186	Print out the results.
192-214	Store variables to be plotted.
218-236	Same as statements 122-140.
237	If the altitude is less than 21000 m, finish plotting at statement 240.
238	If 500 variables are stored, begin plotting at statement 240.
240	Begin plotting the following seven graphs as a function of altitude or time.
242	rocket position - m
259-275	rocket speed - m/s
276-294	horizontal winds - m/s
296-306	air and sensor temperature - °K
308-317	sensor frequency
319-349	air temperature corrections - °K
352-359	standard air pressure - mb.
360	End of the plotting loop.
361-369	Redefine the plotting indexes to minimize pen movement.
370-382	Establish plot continuity.
384	If altitude is less than 21000 m, rewind the tapes.
385	Print a heading for each page of printout.
391	Go back to the beginning of the cycle (statement 161) and read in another radar record.
393-394	Rewind radar tape A, and temperature tape B.

Statement	Description
397	Call INTEG subroutine to obtain atmospheric pressure and density.
398-399	Store pressure in Z1 and density in Z2.
	The following six plots are of the atmospheric parameters as a function of altitude.
400-406	pressure
408-417	density
418-428	viscosity
429-439	speed of sound
440-450	thermal conductivity
451-462	mean free path
464	End of plotting.
465	Return to the MAIN program.
466-474	Format statements for heading printout.
475	End of DRIVER subroutine.

ATMO SUBROUTINE

The purpose of this subroutine is to calculate the standard atmosphere values of pressure and temperature.

Statement	Description
7	Dummy storage arrays for inverting the standard altitude and pressure.
8	If LLL = 1, go to statement 20.
9-12	Scale the standard temperature coefficients.
13-16	Invert the standard atmospheric pressure versus altitude and store in SAM and SIT.
17-19	Store the inverted standard atmosphere back into the original arrays.

Statement	Description
20-23	Search altitude for the corresponding standard temperature coefficients.
24-31	Evaluate the standard temperature and store in TAIR and STAIR.
32-36	Search altitude to find the standard pressure.
37	Linear interpolate to calculate the standard pressure, p.
38	Return to DRIVER subroutine.
39	End of ATMO subroutine.

WIND SUBROUTINE

The purpose of the subroutine WIND is to calculate gravity, horizontal winds, and drag on the parachute. Inputs to this subroutine are the first and second derivatives of position with respect to time.

Statement	Variable	Description
8		If LLL = 1, go to statement 17.
10	GRAV	Gravity at the rocketsonde station = 9.79976.
13	RADUS	Radius of the earth at the rocketsonde station.
17	G	Gravity as a function of altitude, ZOT.
	ZOT	Altitude
19	XD	dx/dt
	YD	dy/dt
	ZD	dz/dt
	VEL	Air speed of the rocketsonde.
20	ZDD	d^2z/dt^2
21	XDD	d^2x/dt^2
	WX	South wind.

Statement	Variable	Description
22	YDD WY	d^2y/dt^2 North wind.
23	RXV	Relative air speed in the south direction.
24	RYV	Relative air speed in the east direction.
26	RTV	Relative air speed of the rocketsonde.
28	DRAG	Drag force on the rocketsonde.
29		Return to DRIVER subroutine.
30		End of WIND subroutine.

INTEG SUBROUTINE

The purpose of subroutine INTEG is used to obtain atmospheric pressure and density given altitude, air temperature, gravity, and an initial pressure from radiosonde data.

Statement	Description
4	ATD = altitude BTMP = air temperature CGR = gravity
5	A, B = radiosonde altitude and pressure.
6	XO = molecular weight of the atmosphere.
7	R = universal gas constant.
8	After the first altitude, go to statement 17.
10-13	If the altitude, ATD, is between A_{i+1} and A_i, go to statement 14.
14	Calculate pressure by linearly interpolating into the radiosonde pressure.

Statement	Description
15	Calculate air density, DEN.
16	Return to DRIVER subroutine.
22-23	If the altitude, ATD, is equal to the first or last altitude of the flight, go to statement 33.
24-32	Fit two Lagrange polynomials to CGR*XO/(R*BTMP) at the altitudes ATD_{j-1}, ATD_j, ATD_{j+1}. The coefficients of the polynomial are C, D, E.
34-41	At the first and last altitude of flight, set the polynomials equal by equating their coefficients.
42-44	Integrate the average of the polynomials, XINT, and evaluate the air pressure, PRESS, (see Chapter III, Eq. 53).
45	Compute air density, DEN.
46	Return to DRIVER subroutine.
47	End of INTEG subroutine.

GRAF SUBROUTINE

The GRAF subroutine is used to plot a rectangular grid, tick marks, and annotation. The following scale, in inches, is used for tickmarks and annotation:

tick marks: $(\text{length of axis}/12.0)^{1/4}/8.0$

annotation: $(\text{length of axis}/12.0)^{1/4}/7.0$

Statement	Variable	Description
1-2	HEAD1	Annotation for the X-axis.
	HEAD2	Annotation for the Y-axis.
	NC1	Number of characters in the X-axis annotation.

Statement	Variable	Description
	NC2	Number of characters in the Y-axis annotation.
	XST	Starting X value.
	XEND	Ending X value.
	YST	Starting Y value.
	YEND	Ending Y value.
	XDIV	X value per division.
	YDIV	Y value per division.
	XLT	Length of the X-axis in inches.
	YLT	Length of the Y-axis in inches.
	MM	Abscissa of the graph origin in inches.
	NN	Ordinate of the graph origin in inches.
	N	Number of digits to the right of the decimal place for number annotation.
5-6		YZ1, XZ2 are scale factors for tick marks in the Y and X directions.
7-8		Z3, Z4 are scale factors for annotation in the Y and X direction.
9		Begin DO loop for plotting the four sides of a grid.
10-13		Plot the left most Y-axis and number annotation. MA = number of divisions on the axis. YNUM = value of Y at the tick mark.
24-34		Plot the top X-axis.
35-45		Plot the right most Y-axis.
46-59		Plot the bottom X-axis and number annotation. XNUM = value of X at the tick mark.
61-66		Plot the label on the lower X-axis and the right most Y-axis.
67		Return to DRIVER subroutine.
68		End of GRAF subroutine.

RATIO SUBROUTINE

Subroutine RATIO takes a given time from the averaged radar data and finds the corresponding temperature frequency and reference frequency from the temperature data. Using the sensor calibration curve and linear interpolation, a sensor temperature in degrees Kelvin corresponding to the ratio of these two frequencies is obtained. In addition, the temperature tape is read if the averaged radar time exceeds that of the temperature data.

Statement	Variable	Description
3		Calibration curve.
	FR	Frequency ratio.
	TEP	Temperature (°C).
	FMRK1	Minimum frequency ratio.
	FMRK2	Maximum frequency ratio.
4	S	Storage array for the temperature tape.
5	X	Time.
	Y	Sensor frequency.
6	C	Coefficients of the quadratic fit to the reference frequency.
9	C1	Reference frequency.
10-13		Search for time in the temperature data corresponding to the radar time, TIM.
15		If TIM is greater than the temperature data, go to statement 43 and read another record from the temperature tape.
16-17	C2	Linear interpolate to find the temperature frequency.
19	RATIO	Compute the frequency ratio.

Statement	Variable	Description
20-21		If RATIO is outside of the calibration curve, go to the error statement 53.
22-29		Search the calibration curve for a corresponding frequency ration.
32-34		Linear interpolate to obtain the sensor temperature, TEMP (°K).
35		Return to DRIVER subroutine.
36-39		Establish sensor frequency continuity.
43		Read one record of the temperature tape.
45-46		If the sensor frequency is less than 10.0 and greater than 165.0, ignore.
48-49		Store time and sensor frequency in the X and Y arrays.
51		If no frequencies were read in, go to statement 43 and read in a temperature record.
52		Go back to statement 10 and continue the temperature interpolation.
53-58		Error statements.
59		Return to the DRIVER subroutine.
60		End of RATIO subroutine.

FSCINV SUBROUTINE

The purpose of the subroutine FSCINV is to obtain the air temperature given the sensor temperature and air speed. The temperature corrections due to the following heat sources are also computed:

1. thermal conduction, DTCOND

2. aerodynamic heating, DTAERO

3. dynamic lag, DTDYN

4. electric heating, DTELEC

5. radiation, DTRAD

Statement	Description
7	Convection coefficient, CONV. Recovery factor, RECF.
16	CP $\left(C_p\right)$, specific heat of the air at constant pressure. PI (π) SIGMA (σ), Stefan-Boltzmann constant.
18	Call the subroutine ATMO to obtain standard air pressure and an initial air temperature.
19	Store the sensor temperature in TEMP(1).
20-24	At the initial altitude set the temperature of the bead, wire, and film equal to the sensor temperature.
25-31	Compute the convection coefficient, HO, and recovery factor, RF, for the leading edge of the film.
32-35	Compute the convection coefficients and recovery factors for the bead, wire, and film strip along the air flow.
36-37	Calculate an average convection coefficient and recovery factor for the film weighted with the length of the leading edge and the length of the film strip along the air flow.
39	$\mathrm{CAPH} = h + 4\sigma\varepsilon T^3$
40-42	$\lambda = \sqrt{\dfrac{h + 4\sigma\varepsilon T^3}{kV/A}}$, λ = the inverse decay length cm^{-1}
49-50	Three times the decay length for the wire and inner film strip are DEC2(wire), DECAY (inner film strip).
51-52	If DECAY is greater than the length of the film strip (CLFILM), then set DECAY = CLFILM.
54	$\mathrm{TEA} = 3\sigma\varepsilon T^4$
55	$\mathrm{AERO} = rv^2/2C_p$

Statement	Description
56-60	The equilibrium temperature for the bead, wire, and film, TE, are calculated as a linear function of the air temperature. $TE = AK * T_{air} + BK$
62-63	The change in the film temperature, DTFILM, is calculated as a finite difference solution of the heat transfer equation for the film. Change in film temperature during a .5 sec time interval is $T_{fi+1} - T_{fi}$ = DTFILM.
65-66	The average wire temperature is obtained by integrating the temperature distribution over the wire length.
67	Store the average wire temperature in TEMP(2).
69-72	The heat conduction coefficients HK, K_1, and K_2 are calculated.
73	The ratio of convection to conduction coefficients is $SAM = h/\left(HK * K_1\right)$
75-78	The time constants of the bead, wire, film $$\tau = \frac{\rho Cv/A}{h + 4\sigma\varepsilon T^3}$$ and sensor are $$\tau(\text{sensor}) = \frac{\rho Cv/A}{h + 4\sigma\varepsilon T^3 + HK}$$
79-80	The steady state temperature of the sensor is $$TE = \left[\left(h + HK \cdot K_1\right) \cdot T_{air} + h \cdot AERO + TOTRAD + TEA + ELECT + HK \cdot K_2\right] / \left(h + 4\sigma\varepsilon T^3 + HK\right) .$$
81-87	Calculate the air temperature corrections due to extraneous heat sources and time lag.

Statement	Description
89	The air temperature is equal to the sensor temperature plus the sum of the temperature corrections.
91-94	If the difference between the characteristic length of the film (CLF) and three times the decay length of the film (DECAY) is greater than 10^{-3}, set CLF = DECAY and go to statement 31 to recompute h and r for the film.
95	If ALTITD is greater than ZMARK (print out index), go to statement 180.
99-168	Print out block.
180	Increment the film temperature. $T_{fi+1} = T_{fi}$ + DTFILM
181	Return to DRIVER subroutine.
182	End of FSCINV subroutine.

```
      DIMENSION S(800)
      COMMON /STD/ WA(50), WP(50)
      COMMON /TEMP/ X(800), Y(800)
      COMMON /DATAIA/ XL(50),YL(50)
      COMMON /NIT/ II
      COMMON/XXX/LLL
      COMMON /INTP/ FRT(900),TMP(900),FMRK1,FMRK2
      COMMON /VAB/ BS(10), CS(10), AS(300), PO(300),AAS(10)
      COMMON /CAT/ XLAT, XLONG
      CALL SKPFLS (1HB,0,2)
      CALL SKPFLS (1HA,0,15)
      READ 251, (AS(I), PO(I), I = 1,272)
      READ 1, (FRT(I), TMP(I), I = 1,801)
  251 FORMAT(8F10.5)
      READ 150, (AAS(I), I = 1,6)
      READ 151,(BS(I), I = 1,5)
      READ 151, (CS(I), I = 1,5)
      READ 157, XLAT, XLONG
      READ 157, (WP(I), WA(I), I = 1,23)
      FMRK1 = FRT(1)
      FMRK2 = FRT(800)
  151 FORMAT(5F10.4)
  150 FORMAT(6F10.1)
  157 FORMAT(2F10.5)
      LLL = 0
      X(1) = 0.0
      SUM = 0.0
      NP = 0
      IR = 0
      N = 0
      II = 1
    8 CONTINUE
      CALL VARBIN (NW,1HB,S,800)
      DO 2 JJ = 1,NW,2
      IF(S(JJ+1) .LT. 10.0) GO TO 2
      IF(IR .EQ. 0) OZ = S(JJ)
      IF(S(JJ+1) .GT. 165.0) GO TO 4
      X(II) = S(JJ) - 12.0
      Y(II) = S(JJ+1)
      IF(IR .EQ. 1) GO TO 6
      II = II + 1
      GO TO 2
    4 N = N + 1
      IR = 1
      SUM = SUM + S(JJ+1)
      IF(S(J) - S(J-2) .LT. 0.5) GO TO 2
    6 IF(N.LT.40) GO TO 7
      NP = NP + 1
      DIV = N
      YL(NP) = SUM / DIV
      XL(NP) = (OZ + S(JJ))*0.5
    7 CONTINUE
      N = 0
      SUM = 0
      IR = 0
    2 CONTINUE
      IF(II .EQ. 1) GO TO 8
      PRINT 10, II
   10 FORMAT(1X, I6)
      PRINT 104 , (XL(J),YL(J) , J=1,NP )
C.....ATAIAT FITS A LEAST SQUARES CURVE TO THE REFERENCE TEMPERATURE
      CALL ATAIAT(NP)
      CALL DRIVER
    1 FORMAT(6F10.3)
  104 FORMAT( 1H ,2F20.10)
      STOP
      END
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      SUBROUTINE DRIVER
      DIMENSION Z(800)
      DIMENSION HEAD1(6),HEAD2(6),HEAD3(6),HEAD4(6),HEAD5(6),HEAD6(6),
     1HEAD7(6),HEAD8(6),HEAD9(6),HEAD10(6),HEAD11(6),HEAD12(6)
      DIMENSION HEAD13(6),HEAD14(6),HEAD15(6),HEAD16(6),HEAD17(7)
     1,HEAD18(6)
      DIMENSION AB(500,3), ABD(500,4),ZA1(500,5),ZB2(500,3),TO(500),
     1ZD4(500),XX(2), YY(2), ZC3(500,2), ZC4(500)
      DIMENSION Z1(1000), Z2(1000)
      COMMON /DAT/ AAA(1000), BBB(1000), CCC(1000)
      COMMON /YL/ P
      COMMON/XXX/LLL, STAIR
      COMMON /ANT/ T(100),X(100,4),XBAR(100,4),XDOT(100,4),XDDOT(100,4)
      COMMON /ANT/ MF,MB,ML,MS,MK,MJ,MN,N,IQ,TAP,TP,TMLTP
      COMMON /FSCI/ TEMT,TEDOT, ZMARK, DTIME, LRUN
      COMMON /VAB/ BS(10), CS(10), AS(300), PO(300), AAS(10)
      COMMON /GASH/ DTCOND,DTDYN,DTRAD,DTAERO,DTELEC
      COMMON /DIST/ TOO,XR,XS,XD,XDD,YR,YS,YD,YDD,ZR,ZS,ZD,ZDD,TE,TD,II
      COMMON /DIST/ TER,TDD
      COMMON /RFAC/ ZSR(15), ZRB(15), ZRW(15)
      COMMON /CLEN/ CLB,CLW,CLF,CLFILM
      COMMON /REG/ IC, IS, IT, IF
      COMMON /AP/ ZOT, TINF, RHO, VS, AMU, AK, AMFP, RTV,TPINF
      COMMON TOTRAD(3)
      COMMON EPS(5),RHOC(5),D(5),W(5),ZKD(5)
      COMMON S, SMB, ZLL, T1, RO, ZL, XEDGE
    1 FORMAT (4A1)
    2 FORMAT (3F10.3)
    4 FORMAT (2E15.5)
    5 FORMAT (3E15.5)
    6 FORMAT (4E15.5)
C.....READ THE SENSOR PARAMETERS AND RADIATION INPUT
      READ 2, (ZSR(I), ZRB(I), ZRW(I), I=1,13)
      READ 1, IC, IS, IT, IF
      READ 6,CLB,CLW,CLFILM, XEDGE
      READ 2, (TOTRAD(I), I = 1,3 )
      READ 6, (D(I), I=1,4)
      READ 6, (RHOC(I), I=1,4)
      READ 6, (EPS(I) , I = 1,4)
      READ 5, (W(I), I=1,3)
      READ 5, (ZKD(I), I=1,3)
      READ 4, RO, ZL
      READ 6, S, SMB, ZLL, T1
C.....READ THE PLOT ANOTATION
      READ 69, NC1, (HEAD1(I), I = 1,4)
      READ  69, NC2, (HEAD2(I), I = 1,5)
      READ 69, NC3, (HEAD3(I), I = 1,4)
      READ 69, NC4, (HEAD4(I), I = 1,4)
      READ 69, NC5, (HEAD5(I), I = 1,3)
      READ 69, NC6, (HEAD6(I), I = 1,4)
      READ 69, NC7, (HEAD7(I), I = 1,4)
      READ 69, NC8, (HEAD8(I), I = 1,6)
      READ 69, NC9, (HEAD9(I), I = 1,6)
      READ 69, NC10, (HEAD10(I), I = 1,6)
      READ 69, NC11, (HEAD11(I), I = 1,5)
      READ 69, NC12, (HEAD12(I), I = 1,6)
      READ 69, NC13, (HEAD13(I), I = 1,2)
      READ 69, NC14, (HEAD14(I), I = 1,4)
      READ 69, NC15, (HEAD15(I), I = 1,5)
      READ 69, NC16, (HEAD16(I), I = 1,5)
      READ 69, NC17, (HEAD17(I), I =1,6)
      READ 69, NC18, (HEAD18(I), I = 1,5)
   69 FORMAT(I2, 2X,6A6)
      PRINT 100
  100 FORMAT (1H1,31HSONDE CONFIGURATION PARAMETERS:,/)
      PRINT 101, (TOTRAD(I), I = 1,3 )
  101 FORMAT( 19H  TOTAL RADIATION   , 3F10.2 )
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      PRINT 107, (D(I), I=1,4)
  107 FORMAT (1H ,5HD(I):,15X,4E15.5)
      PRINT 108, (RHOC(I), I=1,4)
  108 FORMAT (1H ,9HRHO-C(I):,11X,4E15.5)
      PRINT 109, (EPS(I), I=1,4)
  109 FORMAT(9H EPSILON , 12X, 4E15.5 )
      PRINT 110, (W(I), I=1,3)
  110 FORMAT (1H ,5HW(I):,15X,3E15.5)
      PRINT 111, (ZKD(I), I=1,3)
  111 FORMAT (1H ,6HKD(I):,14X,3E15.5)
      PRINT 112, RO
  112 FORMAT (1H ,3HRO:,17X,E15.5)
      PRINT 113, ZL
  113 FORMAT (1H ,12HWIRE LENGTH:,8X,E15.5)
      PRINT 118, S
  118 FORMAT (1H ,17HFILM STRIP WIDTH:,3X,E15.5)
      PRINT 119, SMG
  119 FORMAT (1H ,5X,13HINNER-LENGTH:,2X,E15.5)
      PRINT 120, ZLL
  120 FORMAT (1H ,5X,13HOUTER-LENGTH:,2X,E15.5)
      PRINT 121, T1
  121 FORMAT (1H ,5X,3HT1:,12X,E15.5)
      IP = 0
      AMASS = 2.33
      AREA = 16.4
      C = AMASS/AREA
      XO = 0.0289644
      R = 8.31432
      NAVG = 5
      ND = 1
      II = 0
      MF = 20
      MB = 1
      IQ = 1
      CLF = CLFILM
      N = 4
      MSTAR = 41
      I = 0
C.....READ RADAR TAPE
      CALL VARBIN(NW,1HA,Z,800)
      DO 8 JJ = MSTAR,NW,20
      I = I + 1
      ILP = 0
      XAVG = 0.0
      YAVG = 0.0
      ZAVG = 0.0
      JLST = JJ + 16
C.....AVERAGE FIVE RADAR WORDS TOGETHER
      DO 15 JJ1 = JJ,JLST,4
      ILP = ILP + 1
      IF(ILP.NE.3) GO TO 14
      T(I) = Z(JJ1)
      TIM = T(I)
      CALL RATIO (TEMPT,TIM,ND,C1)
      X(I,4) = TEMPT
   14 XAVG = XAVG + Z(JJ1+1)
      YAVG = YAVG + Z(JJ1+2)
      ZAVG = ZAVG + Z(JJ1+3)
   15 CONTINUE
      X(I,1) = XAVG / 5.0
      X(I,2) = YAVG / 5.0
      X(I,3) = ZAVG / 5.0
    8 CONTINUE
      ILP = 0
      IZMARK = X(1,3)/10000.
      ZMARK = IZMARK*10000 + 5000
      IF(X(1,3) .LT. ZMARK) ZMARK = IZMARK*10000
C.....ZMARK = 5000 METER INTERVAL PRINT OUT INDEX
      PRINT 123,ZMARK
  123 FORMAT (1H ,F15.8)
C.....CALL INITAL TO OBTAIN INITIAL VALUES OF THE FIRST AND SECOND DER.
      CALL INITAL
      K = 1
      L = 11
      J = 1
      IND = 0
      LL1 = 0
      LET = 0
      LRUN = 0
C.....MAXIMUM PLOT SIZE
      CALL IDPLOT(40.0,26.0)
      CALL PLOT(0.9,0.9,-3)
   10 CONTINUE
C.....READ RADAR TAPE
      CALL VARBIN(NW,1HA,Z,800)
      IF(NW.EQ.0) GO TO 50
      DO 16 JJ=1,NW,20
      JLST = JJ + 16
      N = 3
      MB = 1
C.....CALL DIRSIT TO OBTAIN FIRST AND SECOND DERIVATIVES
      CALL DIRSIT
      ZOT = ZS
      TEMT = TE
      TEDOT = TD
      DTIME = T(2) - TOO
      IF(LLL .EQ. 1) GO TO 421
      PRINT 12
      PRINT 11
      PRINT 13
  421 CONTINUE
C.....CALL WIND TO OBTAIN THE HORIZONTAL WIND
      CALL WIND(     DPRU, WX, WY, G, DRAG)
C.....CALL FSCINV TO OBTAIN AIR TEMPERATURE GIVEN SENSOR TEMPERATURE
      CALL FSCINV
C.....PRINT OUT TIME,POSITION,WIND, AND TEMPERATURE
      PRINT 9,TOO,ZS,TE,TPINF, TEDOT,WX,WY,RTV,ZD,XR,YR
      LRUN = LRUN + 1
      IF(IND .NE. 0) GO TO 51
      IND = 1
      LL1 = LL1 + 1
      LET = LET + 1
C.....STORE VARIABLES TO BE PLOTTED
      AAA(LET) = ZOT
      BBB(LET) = TPINF
      CCC(LET) = G
      AB(LL1,1) = XR
      AB(LL1,2) = YR
      AB(LL1,3) = ZR
      TO(LL1) = TOO
      ABD(LL1,1) = XD
      ABD(LL1,2) = YD
      ABD(LL1,3) = ZD
      ZA1(LL1,1) = DTCOND/5.0
      ZA1(LL1,2) = DTAERO/5.0
      ZA1(LL1,3) = DTDYN/5.0
      ZA1(LL1,4) = DTELEC/5.0
      ZA1(LL1,5) = DTRAD/5.0
      ZB2(LL1,1) = (TE-180.0)/20.0
      ZB2(LL1,2) = (TPINF - 180.0)/20.0
      ZB2(LL1,3) = (STAIR - 180.0)/20.0
      ZC3(LL1,1) = WX*0.05
      ZC3(LL1,2) = WY*0.05
      ABD(LL1,4) = RTV
      ZC4(LL1) = P/5.0E+02
      ZD4(LL1) = C1
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      GO TO 53
   51 IND = 0
   53 IP = IP + 1
      XAVG = 0.0
      YAVG = 0.0
      ZAVG = 0.0
C.....AVERAGE FIVE RADAR WORDS TOGETHER
      DO 20 JJ1 = JJ,JLST,4
      ILP = ILP + 1
      IF(ILP.NE.3) GO TO 21
      TIM = Z(JJ1)
      T(ML) = TIM
      CALL RATIO (TEMPT,TIM,ND,C1)
      X(ML,4) = TEMPT
   21 XAVG = XAVG + Z(JJ1+1)
      YAVG = YAVG + Z(JJ1+2)
      ZAVG = ZAVG + Z(JJ1+3)
   20 CONTINUE
      ILP = 0
      X(ML,1) = XAVG / 5.0
      X(ML,2) = YAVG / 5.0
      X(ML,3) = ZAVG / 5.0
      IF(X(ML,3) .LT. 21000.0) GO TO 41
      IF(LL1 .EQ. 500) GO TO 41
      GO TO 59
   41 DO 71 I = K,L,J
      GO TO (30,31,32,33,34,35,36,37,38,39,40), I
C.....PLOT POSITION OF THE ROCKET
   30 IF(IP .GT. 1200) GO TO 72
      CALL GRAF(HEAD5,HEAD2,NC5,NC2,0.0,1200.0,-80.0,80.0,200.0,20.0,
     16.0,8.0,0,0,1)
      XX(1) = 0.0
      XX(2) = 6.U
      YY(1) = 4.U
      YY(2) = 4.0
      CALL LINE(XX,YY,2,1)
   72 DO 87 JI = 1,3
      JZ = 3
      DO 87 JK = 1,LL1
      A = TO(JK)/200.0
      B = AB(JK,JI)/20000.0 + 4.0
      CALL PLOT(A,B,JZ)
   87 JZ = 2
      GO TO 71
C.....PLOT SPEED OF THE ROCKET
   31 IF(IP .GT. 1200) GO TO 74
      CALL GRAF(HEAD3,HEAD1,NC3,NC1,-200.0,200.0,20.0,80.0,50.0,10.0,
     18.0,6.0,7,0,1)
      XX(1) = 11.0
      XX(2) = 11.0
      YY(1) = 0.0
      YY(2) = 6.0
      CALL LINE(XX,YY,2,1)
   74 DO 75 JI = 1,4
      JZ = 3
      DO 75 JK = 1,LL1
      A = ABD(JK,JI)/50.0 + 11.0
      B = (AB(JK,3) - 20000.0)/10000.0
      CALL PLOT(A,B,JZ)
   75 JZ = 2
      GO TO 71
C.....PLOT THE HORIZONTAL WINDS
   32 IF(IP .GT. 1200) GO TO 77
      CALL GRAF(HEAD4,HEAD1,NC4,NC1,-60.0,60.0,20.0,80.0,20.0,10.0,
     16.0,6.0,16,0,1)
      XX(1) = 19.0
      XX(2) = 19.0
      YY(1) = 0.0
      YY(2) = 6.0
      CALL LINE(XX,YY,2,1)
   77 JZ = 3
      DO 78 JK = 1,LL1
      A = ZC3(JK,2) + 19.0
      B = (AB(JK,3) - 20000.0)/10000.0
      CALL PLOT(A,B,JZ)
   78 JZ = 2
      DO 79 JK = 1,LL1,5
      A = ZC3(JK,1) + 19.0
      B = (AB(JK,3) - 20000.0)/10000.0
   79 CALL SYMBL4(A,B,.10,1H.,0,0,1)
      GO TO 71
C.....PLOT AIR, SENSOR, AND STANDARD TEMPERATURES
   33 IF(IP .GT. 1200) GO TO 80
      CALL GRAF(HEAD7,HEAD1,NC7,NC1,180.0,300.0,20.0,80.0,20.0,10.0,
     1 6.0,6.0,23,0,1)
   80 DO 81 JI = 1,3
      JZ = 3
      DO 81 JK = 1,LL1
      A = ZB2(JK,JI) + 23.0
      B = (AB(JK,3) - 20000.0)/10000.0
      CALL PLOT(A,B,JZ)
   81 JZ = 2
      GO TO 71
C.....PLOT THE SENSOR TEMPERATURE IN FREQUENCY
   34 IF(IP .GT. 1200) GO TO 93
      CALL GRAF(HEAD5,HEAD6,NC5,NC6,0.0,1200.0,0.0,240.0,200.0,40.0,
     16.0, 6.0,30,0,1)
   93 JZ = 3
      DO 94 JK = 1,LL1
      A = ZD4(JK)/40.0
      B = TO(JK)/200.0 + 30.0
      CALL PLOT(B,A,JZ)
   94 JZ = 2
      GO TO 71
C.....PLOT THE AIR TEMPERATURE CORRECTIONS
   35 XL = 3.0
      IF(IP .GT. 1200) GO TO 90
      CALL GRAF(HEAD8,HEAD1,NC8,NC1,-15.0,15.0,20.0,80.0,5.0,10.0,
     16.0,6.0,0,10,1)
      GO TO 90
   36 XL = 10.0
      IF(IP .GT. 1200) GO TO 90
      CALL GRAF(HEAD9,HEAD1,NC9,NC1,-15.0,0.0,20.0,80.0,5.0,10.0,3.0,
     16.0,7,10,1)
      GO TO 90
   37 XL = 13.0
      IF(IP .GT. 1200) GO TO 90
      CALL GRAF(HEAD10,HEAD1,NC10,NC1,-10.0,10.0,20.0,80.0,5.0,10.0,
     14.0,6.0,11,10,1)
      GO TO 90
   38 XL = 17
      IF(IP .GT. 1200) GO TO 90
      CALL GRAF(HEAD11,HEAD1,NC11,NC1,-5.0,5.0,20.0,80.0,5.0,10.0,
     12.0,6.0,16,10,1)
      GO TO 90
   39 XL = 20.0
      IF(IP .GT. 1200) GO TO 90
      CALL GRAF(HEAD12,HEAD1,NC12,NC1,-5.0,5.0,20.0,80.0,5.0,10.0,
     12.0,6.0,19,10,1)
   90 JZ = 3
      DO 92 JK = 1,LL1
      A = ZA1(JK,I-5) + XL
      B = (AB(JK,3) - 20000.0)/10000.0 + 10.0
      CALL PLOT(A,B,JZ)
   92 JZ = 2
      GO TO 71
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C.....PLOT THE STANDARD PRESSURE
   40 IF(IP .GT. 1200) GO TO 99
      CALL GRAF(HEAD13,HEAD1,NC13,NC1,0.0,30.0,20.0,80.0,5.0,10.0,6.0,
     16.0,22,10,1)
   99 DO 201 JK = 1,LL1,5
      A = ZC4(JK) + 22.0
      IF(A .GT. 28.0) A = 28.0
      B = (AB(JK,3) - 20000.0)/10000.0 + 10.0
  201 CALL SYMBL4(A,B,0.1,1H.,0.0,1)
   71 CONTINUE
      IF(K .EQ. 1) GO TO 96
      K = 1
      L = 11
      J = 1
   96 IF(K .EQ. 11) GO TO 97
      K = 11
      L = 1
      J = -1
   97 CONTINUE
      DO 98 I = 1,3
      AB(1,I) = AB(LL1,I)
      ABD(1,I) = ABD(LL1,I)
      ZA1(1,I) = ZA1(LL1,I)
   98 ZB2(1,I) = ZB2(LL1,I)
      TO(1) = TO(LL1)
      ABD(1,4) = ABD(LL1,4)
      ZA1(1,5) = ZA1(LL1,5)
      ZA1(1,4) = ZA1(LL1,4)
      ZD4(1) = ZD4(LL1)
      ZC3(1,1) = ZC3(LL1,1)
      ZC3(1,2)= ZC3(LL1,2)
      ZC4(1) = ZC4(LL1)
      LL1 = 1
      IF(X(ML,3) .LT. 21000.0) GO TO 50
   50 IF(LRUN.LT.52) GO TO 16
      LRUN = 0
      PRINT 12
      PRINT 11
      PRINT 13
   16 CONTINUE
      GO TO 10
C.....REWIND THE TEMPERATURE AND RADAR TAPES
   50 CALL REWND(1HA,0)
      CALL REWND(1HB,0)
C.....CALL INTEG TO OBTAIN PRESSURE AND DENSITY
      DO 207 I = LET,1,-1
      CALL INTEG(I,LET,PRES,DEN)
      Z1(I) = PRES
  207 Z2(I) = DEN
      JZ = 3
C.....PLOT THE PRESSURE
      DO 209 I = 1,LET
      A = Z1(I)/5.0E+02 + 22.0
      IF(A .GT. 28.0) A = 28.0
      B = (AAA(I) - 20000.0)/10000.0 + 10.0
      CALL PLOT(A,B,JZ)
  209 JZ = 2
      CALL PLOT(0.0,18.0,-3)
C.....PLOT DENSITY
      CALL GRAF(HEAD14,HEAD1,NC14,NC1,0.0,5.0,20.0,80.0,1.0,
     110.0,5.0,6.0,0,1)
      JZ = 3
      DO 211 I = 1,LET
      A = Z2(I)*1.0E+02
      IF(A .GT. 5.0) A = 5.0
      B = (AAA(I) - 20000.0)/10000.0
      CALL PLOT(A,B,JZ)
  211 JZ = 2
C.....PLOT VISCOSITY
      CALL GRAF(HEAD15,HEAD1,NC15,NC1,0.0,5.0,20.0,80.0,1.0,10.0,5.0,
     16.0,6,0,1)
      JZ = 3
      DO 213 I = 1,LET
      A1 = 1.458E-06*BBB(I)*(3./2.)/(BBB(I)+110.4)
      A = A1/(3.0E-06) + 6.0
      IF(A .GT. 11.0) A = 11.0
      B = (AAA(I) - 20000.0)/10000.0
      CALL PLOT(A,B,JZ)
  213 JZ = 2
C.....PLOT SPEED OF SOUND
      CALL GRAF(HEAD16,HEAD1,NC16,NC1,0.0,4.0,20.0,80.0,1.0,10.0,4.0,
     16.0,12,0,1)
      JZ = 3
      DO 215 I = 1,LET
      A1 = SQRT(1.4*R*BBB(I)/XO)
      A = A1/100.0 + 12.0
      IF(A .GT. 16.0) A = 16.0
      B = (AAA(I) - 20000.0)/10000.0
      CALL PLOT(A,B,JZ)
  215 JZ = 2
C.....PLOT THERMAL CONDUCTIVITY
      CALL GRAF(HEAD17,HEAD1,NC17,NC1,0.0,5.0,20.0,80.0,1.0,10.0,5.0,
     16.0,17,0,1)
      JZ = 3
      DO 217 I = 1,LET
      A1=6.325E-07*BBB(I)**(3./2.)/(BBB(I)+245.4*10.**(-12./BBB(I)))
      A = A1*4186.0465*2.0E+02 + 17.0
      IF(A .GT. 22.0) A = 22.0
      B = (AAA(I) - 20000.0)/10000.0
      CALL PLOT(A,B,JZ)
  217 JZ = 2
C.....PLOT MEAN FREE PATH
      CALL GRAF(HEAD18,HEAD1,NC18,NC1,0.0,4.0,20.0,80.0,1.0,10.0,4.0,
     16.0,23,0,1)
      JZ = 3
      DO 219 I = 1,LET
      A1=R*BBB(I)/(Z1(I)*(2.**.5)*3.1415926*6.02257E+26*(3.65E-10)**2)*
     11.0E+03
      A = A1/(2.0E-05) + 23.0
      IF(A .GT. 27.0) A = 27.0
      B = (AAA(I) - 20000.0)/10000.0
      CALL PLOT(A,B,JZ)
  219 JZ = 2
C.....END PLOTS
      CALL FINI
      RETURN
    9 FORMAT (1H ,F9.3,F12.2,3F13.4,3F12.4,3F10.2)
   12 FORMAT (1H1,3X,4HTIME,6X,8HALTITUDE,3X,11H   SENSOR  ,2X,11H    AIR
     1       ,2X,11HSENSOR TEMP,4X,6HNORTH ,6X,6HEAST  ,5X,8H   AIR   ,
     210H    FALL   , 4X, 16HPOSITION(METERS)    )
   11 FORMAT(26X,11HTEMPERATURE,2X,11HTEMPERATURE,1X,11H     RATE   ,
     13X,9H   WIND  ,3X,9H   WIND   ,3X,7H SPEED  ,5X,10H    RATE    ,
     210H   EAST     , 10H  NORTH         )
   13 FORMAT(3X,3HSEC,9X,5HMETER,9X,5HDEG K,8X,5HDEG K,8X,5HDEG K,4X,
     16H M/SEC,6X,6H M/SEC,7X,6H M/SEC,2X,6H M/SEC / )
      END
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      SUBROUTINE FSCINV
C.....FSCINV COMPUTES AIR TEMPERATURE GIVEN SENSOR TEMPERATURE
      DIMENSION  TE(5), ZLAMDA(5), AK(5), BK(5), TEMP(5)
      DIMENSION  CAPH(5), AERO(5),                       TEA(5), TAU(5)
      COMMON /BASH/ DTCOND,DTDYN,DTRAD,DTAERO,DTELEC
      COMMON /CLEN/ CLB, CLW, CLF, CLFILM
      COMMON/HR/ CONV(3), RECF(3)
      COMMON/AP/ ALTITD, TINF, RHO, VS, AMU, AA, AMFP, VEL, TAIR
      COMMON /XXX/ LLL
      COMMON/FSCI/ TBEAD, TSDOT, ZMARK, DTIME, LRUN
      COMMON /YL/ P
      COMMON /XXY/ IRB, IRW, IRF
      COMMON TOTRAD(3)
      COMMON EPS(5), RHOC(5), D(5), ELECT(5), ZKD(5)
      COMMON S, XIN, XOUT, T1, RO, XWIRE, XEDGE
      DATA  CP,PI,SIGMA/1003., 3.1416, 5.6687E-8/
C.....OBTAIN STANDARD TEMPERATURE AND PRESSURE
  337 CALL ATMO
      TEMP(1) = TBEAD
      IF(LLL .EQ. 1) GO TO 10
      LLL = 1
C.....INITIALLY SET THE SENSOR TEMPERATURE EQUAL TO THE BEAD TEMPERATURE
      DO 20 I = 1,4
   20 TEMP(I) = TBEAD
   10 IK = 1
      CLF1 = CLF
      CLF = S
C.....COMPUTE CONVECTION COEFICIENTS AND RECOVERY FACTORS
      CALL HANDR(IK)
      HO = CONV(3)
      RF = RECF(3)
      IK = 0
      CLF = CLF1
      CALL HANDR(IK)
      HH1 = CONV(3)
      CONV(3) = ((CONV(3)*CLF + HO*XEDGE)/(CLF+XEDGE)+CONV(3))/2.0
      RECF(3) =((RECF(3)*CLF + RF*XEDGE)/(CLF+XEDGE)+RECF(3))/2.0
      DO 30 I = 1,3
   30 CAPH(I) = CONV(I) + 4.*SIGMA*EPS(I)*TEMP(I)**3
C.....COMPUTE DECAY LENGTHS
      ZLAMDA(2) = SQRT(4.*CAPH(2)/ZKD(2))
      ZLAMF2 = SQRT(2.0*(HH1+4.0*SIGMA*EPS(4)*TEMP(3)**3)/ZKD(3))
      ZLAMDA(3) = SQRT(2.*CAPH(3)/ZKD(3))
      ARG1 = ZLAMDA(2)*XWIRE
      ARG2 = ZLAMDA(3)*XOUT
      ARG3 = ZLAMF2*XIN
      CWB=ZKD(2)*D(2)/(2.*D(1)**2)
      CWF=PI*D(2)*ZKD(2)/(4.*ZKD(3)*S)
      DEC2 = 3.0/ZLAMDA(2)
      DECAY = 3./ZLAMF2
      IF(DECAY .LE. CLFILM) GO TO 51
      DECAY = CLFILM
   51 DO 40 I = 1,3
      TEA(I)=3.*SIGMA*EPS(I)*TEMP(I)**4
      AERO(I) = RECF(I)*VEL**2/(2.*CP)
      AK(I) = CONV(I)/CAPH(I)
      BK(I)=(CONV(I)*AERO(I)+TOTRAD(I)+TEA(I)+ELECT(I))
     1/CAPH(I)
C.....TE = EQUILIBRIUM TEMPERATURE
   40 TE(I) = AK(I)*TAIR + BK(I)
C.....CHANGE IN FILM TEMPERATURE
      DTFILM=2.0/(2.*RHOC(4)*D(4)+   D(3)*RHOC(3))     *DTIME*(CONV(3)
     1*(TAIR+AERO(3)-TEMP(3))+TOTRAD(3)-SIGMA*EPS(3)*TEMP(3)**4)
C.....AVERAGE WIRE TEMPERATURE
      TWIRE=TE(2)+(TEMP(3)-TE(2)-(TEMP(1)-TE(2))*COSH(ARG1))*(COSH(ARG1)
     1-1.)/(SINH(ARG1)*ARG1)+(TEMP(1)-TE(2))*SINH(ARG1)/ARG1
      TEMP(2) = TWIRE
C.....COMPUTE CONDUCTION PARAMETERS
      HK=ZKD(2)*D(2)*ZLAMDA(2)/(2.*D(1)**2*TANH(ARG1))
      AK1=CONV(2)*(1.-1./COSH(ARG1))/CAPH(2)
      AK2=(1.-1./COSH(ARG1))*(CONV(2)*AERO(2)+TOTRAD(2)+TEA(2))/CAPH(2
     1+TEMP(3)/COSH(ARG1)
      SAM = CONV(1)/(HK*AK1)
C.....COMPUTE TIME CONSTANTS
      TAU(3) = (2.*RHOC(4)*D(4)+   D(3)*RHOC(3))/(2.*CAPH(3))
      TAU(2)=RHOC(2)*D(2)/(4.*CAPH(2))
      TAU(1)=RHOC(1)*D(1)/(6.*CAPH(1))
      TAU(4)=RHOC(1)*D(1)/(6.*(CAPH(1)+HK))
      TE(4)=((CONV(1)+HK*AK1)*TAIR+CONV(1)*AERO(1)+TOTRAD(1)+TEA(1)
     1+ELECT(1)+HK*AK2)/(CAPH(1)+HK)
      DENOM = CONV(1) + HK*AK1
C.....COMPUTE AIR TEMPERATURE CORRECTIONS
      DTCOND = HK*((1.-AK1)*TEMP(1)-AK2)/DENOM
      DTDYN = RHOC(1)*D(1)*TSDOT/(6.*DENOM)
      DTRAD = -(TOTRAD(1)-SIGMA*EPS(1)*TEMP(1)**4)/DENOM
      DTAERO = -CONV(1)*AERO(1)/DENOM
      DTELEC = -ELECT(1)/DENOM
C.....COMPUTE AIR TEMPERATURE
      TAIR = TBEAD+DTCOND+DTRAD+DTAERO+DTELEC+DTDYN
C.....FIND THE LENGTH OF FILM TO COMPUTE H AND R
   15 DCLF = ABS(DECAY - CLF)
      IF(DCLF .LT. 1.0E-03) GO TO 70
      CLF = DECAY
      GO TO 10
   70 IF(ALTITD .GT. ZMARK) GO TO 341
      ZMARK = ZMARK - 5000.0
      SONG = ZMARK + 5000.0
C.....PRINT OUT BLOCK
      PRINT 431, SONG
  431 FORMAT(1H1, 50X, F10.2 , 12H     METERS    )
      PRINT 399
  399 FORMAT(   /24H  ATMOSPHERIC PARAMETERS  )
      PRINT 400, ALTITD,TBEAD,P,RHO,VS,AMU,AA,AMFP
  400 FORMAT( ' ALTITUDE(     METER)=' ,E20.5/' SENSOR TEMP(DEG K)='  ,
     1G20.4/' PRESSURE(NEWTON/M**2)=' ,E20.4/' DENSITY(KGM/M**3)=' ,
     2E20.4/' VELOCITY OF SOUND(M/SEC)=' ,G20.4/' VISCOSITY(KGM/(M*S
     3=' ,E20.4/'THERMAL CONDUCTIVITY(WATTS/METER)=' ,E20.4/' MEAN F
     4PATH(METER)=', E20.4    )
      PRINT 401
  401 FORMAT(   / 29H  HEAT CONDUCTION PARAMETERS  )
      PRINT 402
  402 FORMAT( / 48X,5H BEAD,15X,5H WIRE,15X,5H FILM,14X,6HSENSOR    )
      PRINT 403, HK, AK1, AK2
  403 FORMAT(5X,'HK(WATTS/(M**2*DEG K))=',67X,G20.4 /5X,'K1=',87X,G
     15X, 'K2(DEG K)=' 81X, G20.4 )
      PRINT 404,              ZLAMDA(2), ZLAMF2
  404 FORMAT(5X, 'LAMDA(1/METER)=',35X, 2G20.4)
      PRINT 405,          DEC2, DECAY
  405 FORMAT(5X,'3*DECAY LENGTH(METER)=',28X,2G20.4 )
      PRINT 406, DTCOND
  406 FORMAT(5X, 'CONDUCTION TEMP CORRECTION(DEG K)=',54X,G20.3 )
      PRINT 407
  407 FORMAT(   / 32H  AERODYNAMIC HEATING PARAMETERS  )
      PRINT 402
      PRINT 408, (CONV(I) , I = 1,3)
  408 FORMAT(5X,'CONV COEF(WATTS/(M**2*DEG K))= ' , 3G20.4 )
      PRINT 409, (RECF(I), I = 1,3)
  409 FORMAT(5X,22H  RECOVERY COEFICIENT=, 8X, 3G20.4 )
      PRINT 411, IRB, IRW, IRF
  411 FORMAT(5X,14H  FLOW REGION= , 16X, 3(14X,A6))
      PRINT 410, (AERO(I), I = 1,3)
  410 FORMAT(5X,'AERODYN HEAT(  DEG K)=' ,8X, 3G20.4 )
      PRINT 412, DTAERO
  412 FORMAT(5X,' AERODYNAMIC TEMP CORRECTION(DEG K)=', 53X,G20.3)
      PRINT 413
```

```
  413 FORMAT(   / 24H  DYNAMIC LAG PARAMETERS  )
      PRINT 402
      PRINT 415, (TAU(I), I = 1,4)
  415 FORMAT(5X, 'TIME CONSTANT(SEC)=' ,11X, 4G20.4 )
      PRINT 437, (TEMP(I), I = 1,3)
  437 FORMAT(5X,' TEMPERATURE(DEG K)=' ,10X, 3G20.4 )
      PRINT 416 , (TE(I), I = 1,4)
  416 FORMAT(5X, ' EQUILIBRIUM TEMP(DEG K)=' ,5X, 4G20.4 )
      PRINT 422, (AK(I), I = 1,3)
  422 FORMAT(5X,8H  AK(I)= , 22X,3G20.4 )
      PRINT 423, (BK(I), I = 1,3)
  423 FORMAT(5X, 'BK(I)(DEG K)=' ,17X, 3G20.4 )
      PRINT 439, TSDOT
  439 FORMAT(5X,' TEMP TIME DER(DEG K/SEC)=' , 64X, G20.3)
      PRINT 417, DTDYN
  417 FORMAT(5X, ' DYNAMIC TEMP LAG CORRECTION(DEG K)=', 53X, G20.3 )
      PRINT 418
  418 FORMAT(   / 30H  RADIATION HEATING PARAMETERS   )
      PRINT 402
      PRINT 420, (TOTRAD(I), I = 1,3)
  420 FORMAT(5X, ' TOTAL RADIATION INPUT(W/M**2)=' , 3G20.4 )
      PRINT 424, DTRAD
  424 FORMAT(5X, ' RADIATION TEMP CORRECTION(DEG K)=', 55X, G20.3 )
      PRINT 425
  425 FORMAT(   / 29H  ELECTRIC HEATING PARAMETERS   )
      PRINT 402
      PRINT 426, ELECT(1)
  426 FORMAT(5X, 'ELECTRIC HEATING(WATTS/M**2)=' ,63X, G20.3 )
      PRINT 427, DTELEC
  427 FORMAT(5X, ' ELECTRIC TEMP CORRECTION(DEG K)=' 55X, G20.3 /1H1 )
  339 PRINT 12
      PRINT 11
      PRINT 13
      LRUN = 0
  341 CONTINUE
   12 FORMAT (1H1,3X,4HTIME,6X,8HALTITUDE,3X,11H   SENSOR  ,2X,11H   AIR
     1      ,2X,11HSENSOR TEMP,4X,6HNORTH ,6X,6HEAST  ,5X,8H   AIR   ,
     210H    FALL   , 4X, 16HPOSITION(METERS)    )
   11 FORMAT(26X,11HTEMPERATURE,2X,11HTEMPERATURE,1X,11H    RATE   ,
     13X,9H   WIND  ,3X,9H   WIND  ,3X,7H SPEED  ,5X,10H   RATE   ,
     210H   EAST   , 10H  NORTH      )
   13 FORMAT(3X,3HSEC,9X,5HMETER,9X,5HDEG K,8X,5HDEG K,8X,5HDEG K,4X,
     16H M/SEC,6X,6H M/SEC,7X,6H M/SEC,2X,6H M/SEC / )
C.....INCREMENT THE FILM TEMPERATURE
      TEMP(3) = TEMP(3) + DTFILM
      RETURN
      END
```

```
      SUBROUTINE WIND(     DPRU, WX, WY, G, DRAG)
C.....WIND COMPUTES HORIZONTAL WINDS
      COMMON /AP/ ZOT, TINF, RHO, VS, AMU, AK, AMFP, RTV, TAIR
      COMMON/DIST/TOO,XR,XS,XD,XDD,YR,YS,YD,YDD,ZR,ZS,ZD,ZDD,TE,TD,II,
     1TER,TDD
      COMMON /CAT/ XLAT, XLONG
      COMMON /XXX/ LLL
      IF(LLL .EQ. 1) GO TO 101
C.....COMPUTE GRAVITY
      GRAV = 9.79976
      XX = (6378.099*1.0E+03)**2
      ZZ = (6356.631*1.0E+03)**2
      RADUS=SQRT(XX*ZZ/(XX*SIN(XLAT)**2+ZZ*COS(XLAT)**2))
      GA = 3.0*GRAV/RADUS**2
      GB = -2.0*GRAV/RADUS
      GC = GRAV
  101 G = GA*ZOT**2 + GB*ZOT + GC
C.....ABSOLUTE AIR SPEED
      VEL=SQRT(XD**2+YD**2+ZD**2)
      DPRU=(ZDD+G)/ZD
      WX=-(XDD/DPRU)+XD
      WY=-(YDD/DPRU)+YD
      RXV=XD-WX
      RYV=YD-WY
C.....RELATIVE AIR SPEED
      RTV=SQRT(RXV**2+RYV**2+ZD**2)
C.....DRAG FORCE
      DRAG = DPRU*RTV
      RETURN
      END
```

```
      SUBROUTINE ATAIAT (NP)
C.....ATAIAT FITS A LEAST SQUARES CURVE TO THE REFERENCE TEMPERATUR
      COMMON /DATAIA/ XL(50),YL(50)
      COMMON /TATA/ C(4)
      DIMENSION A(4,4) , B(4,50)
      N = 3
      MD = NP
      SUM1 = 0.0
      SUM2 = 0.0
      SUM3 = 0.0
      SUM4 = 0.0
      DO 1 K=1,MD
      DELTK = XL(K)
      SUM1 = SUM1 + DELTK
      D2 = DELTK*DELTK
      SUM2 = SUM2 + D2
      D3 = D2*DELTK
      SUM3 = SUM3 + D3
      D4 = D3 * DELTK
      SUM4 = SUM4 + D4
    1 CONTINUE
      AB1 = SUM2*MD - SUM1*SUM1
      AB2 = SUM3*MD - SUM1*SUM2
      AB3 = SUM3*SUM1 - SUM2*SUM2
      DET = SUM4*AB1
      DET1 = SUM3*AB2
      DET2 = SUM2*AB3
      DETR = DET - DET1 + DET2
      A(1,1) = AB1/DETR
      A(2,1) = -AB2/DETR
      A(3,1) = AB3/DETR
      A(1,2) = A(2,1)
      A(2,2) = (SUM4*MD - SUM2*SUM2)/DETR
      A(3,2) =-(SUM4*SUM1 - SUM2*SUM3) / DETR
      A(1,3) = A(3,1)
      A(2,3) = A(3,2)
      A(3,3) = (SUM4*SUM2 - SUM3*SUM3)/DETR
      DO 3 J=1,MD
      DELTJ = XL(J)
      DELT2 = DELTJ*DELTJ
      DO 3 K=1,N
      B(K,J) = A(K,1)*DELT2 + A(K,2)*DELTJ + A(K,3)
    3 CONTINUE
      DO 5 J=1,MD
      DO 5 I = 1,N
      C(I) = C(I) + B(I,J)*YL(J)
    5 CONTINUE
      PRINT 51 , (C(I) ,I=1,3 )
      DO 6 JJ = 1,MD
      XX = XL(JJ) * XL(JJ)
      VAL = C(1) * XX + C(2) * XL(JJ) + C(3)
      PRINT 51, VAL ,XL(JJ) , YL(JJ)
    6 CONTINUE
   51 FORMAT (1H , 3F20.10 )
      RETURN
      END
```

```
      SUBROUTINE GRAF(HEAD1,HEAD2,NC1,NC2,XST,XEND,YST,YEND,XDIV,YDIV,
     1XLT,YLT,MM,NN,N)
C.....GRAF DRAWS A RECTANGULAR  GRID FOR PLOTTING
      DIMENSION HEAD1(6), HEAD2(6)
      YZ1 = (YLT/12.0)**.25/8.0
      XZ2 = (XLT/12.0)**.25/8.0
      Z3 = (YLT/12.0)**.25/7.0
      Z4 = (XLT/12.0)**.25/7.0
      DO 20 I = 1,4
      IF(I .NE. 1) GO TO 30
      A = MM
      B = NN
      CALL NUMBER(A-.2 ,B,YZ1,YST,90.0,N)
      CALL PLOT(A,B,3)
      MA = (YEND-YST)/YDIV
      Y = B
      DO 40 J = 1,MA
      B = Y + YLT/MA*J
      CALL PLOT(A,B,2)
      CALL PLOT(A+YZ1,B,2)
      YNUM = YST + YDIV*FLOAT(J)
      CALL NUMBER(A-.2 ,B-.2 ,YZ1,YNUM,90.0,N)
   40 CALL PLOT(A,B,3)
   30 IF(I .NE. 2) GO TO 50
      A = MM
      B = NN + YLT
      X = A
      CALL PLOT(A,B,3)
  100 MA = (XEND - XST)/XDIV
      DO 60 J = 1,MA
      A = X + XLT/MA*J
      CALL PLOT(A,B,2)
      CALL PLOT(A,B-XZ2,2)
   60 CALL PLOT(A,B,3)
   50 IF(I .NE. 3)  GO TO 70
      A = MM + XLT
      B = NN + YLT
      CALL PLOT(A,B,3)
      MA = (YEND - YST)/YDIV
      Y = B
      DO 80 J = 1,MA
      B = Y - YLT/MA*J
      CALL PLOT(A,B,2)
      CALL PLOT(A+YZ1,B,2)
   80 CALL PLOT(A,B,3)
   70 IF(I .NE. 4) GO TO 20
      A = MM + XLT
      B = NN
      CALL NUMBER(A-.22,B+.22,XZ2,XEND,0.0,N)
      CALL PLOT(A,B,3)
      MA = (XEND - XST)/XDIV
      X = A
      DO 90 J = 1,MA
      A = X - XLT/MA*J
      CALL PLOT(A,B,2)
      CALL PLOT(A,B+XZ2,2)
      XNUM = XEND - FLOAT(J)*XDIV
      CALL NUMBER(A-.2 ,B-.2 ,XZ2,XNUM,0.0,N)
   90 CALL PLOT(A,B,3)
   20 CONTINUE
      XX = MM + XLT/2.0 - Z4*NC1*6.0/14.0
      YY = NN - 0.5
      CALL SYMBL4(XX,YY,Z4,HEAD1,0.0,NC1)
      XX = MM - 0.5
      YY = NN + YLT/2.0 - Z3*NC2*6.0/14.0
      CALL SYMBL4(XX,YY,Z3,HEAD2,90.0,NC2)
      RETURN
      END
```

```
      SUBROUTINE RATIO(TEMP,TIM,ND,C2)
C.....RATIO EVALUATES TEMPERATURE(K) GIVEN FREQUENCY
      COMMON /INTP/ FR(900),TEP(900),FMRK1,FMRK2
      DIMENSION S(800)
      COMMON /TEMP/ X(800), Y(800)
      COMMON /TATA/ C(4)
      COMMON /MIT/ II
      C(1) = -.0000168652
      C(2) = .0124469306
      C(3) = 185.8372497559
      T = TIM * TIM
      C1 = C(1) * T + C(2) * TIM + C(3)
   55 DO 33 I = ND,II
      N = I + 1
      IF( TIM . LT.X(N)) GO TO 44
   33 CONTINUE
   44 ND = N - 2
      IF(TIM .GE. X(II)) GO TO 131
      SLP = (Y(N) - Y(I)) /(X(N) -X(I))
      C2 = SLP * (TIM - X(I)) + Y(I)
C.....C1 = REFERENCE FREQUENCY C2 = SENSOR FREQUENCY
      RATIO = C2 / C1
      IF(RATIO.LT.FMRK1) GO TO 12
      IF(RATIO.GT.FMRK2) GO TO 12
      DO 1 I = 1,800,10
      N = I
      IF(RATIO.LT.FR(I)) GO TO 2
    1 CONTINUE
    2 MD = N - 11
      DO 3 I = MD,N
      IF(RATIO.LT.FR(I)) GO TO 4
    3 CONTINUE
C.....LINEAR INTERPOLATE IN THE CALIBRATION CURVE TO OBTAIN TEMPERATURE
    4 LL = I - 1
      SLP = (TEP(LL) - TEP(I)) /(FR(LL) - FR(I))
      TEMP = SLP * (RATIO - FR(I)) + TEP(I)
      TEMP = TEMP + 273.15
      RETURN
  131 X(1) = X(II-1)
      X(2) = X(II)
      Y(1) = Y(II-1)
      Y(2) = Y(II)
      II = 2
      ND = 1
C.....READ THE TEMPERATURE TAPE
  141 CALL VARBIN(NW,1HB,S,800)
      DO 150 I = 1,NW,2
      IF(S(I+1) .LT. 10.0) GO TO 150
      IF(S(I+1) .GT. 165.0) GO TO 150
      II = II + 1
      X(II) = S(I) - 12.0
      Y(II) = S(I+1)
  150 CONTINUE
      IF(II .LE. 2) GO TO 141
      GO TO 55
   12 PRINT 13,RATIO,TIM,C1,C2,FMRK1,FMRK2,ND
   13 FORMAT(27H OUT OF INTERPOLATING RANGE ,6F15.8, I6)
      NZ1 = ND - 20
      NZ2 = ND + 20
      PRINT 101, (X(I), Y(I), I = NZ1, NZ2)
  101 FORMAT( 7H  TIME=, E15.8, 7H  FREQ= , E15.8)
   20 RETURN
      END
```

```
      SUBROUTINE ATMO
C.....ATMO COMPUTES STANDARD TEMPERATURE AND PRESSURE
      COMMON /XXX/ LLL, STAIR
      COMMON /VAB/ B(10), C(10), A(300), PO(300),AA(10)
      COMMON /YL/ P
      COMMON /AP/ ALT, TINF, RHO, VS, AMU, AK, AMFP, VEL, TAIR
      DIMENSION SIT(300), SAM(300)
      IF(LLL .EQ. 1) GO TO 57
      DO 25  I = 1,5
      IF(I .EQ. 3) GO TO 25
      C(I) = C(I)*1.0E-03
   25 CONTINUE
      DO 250 I = 1,272
      J = 273 - I
      SIT(I) = A(J)*1.0E+03
  250 SAM(I) = PO(J)*1.0E+02
      DO 207 I = 1,272
      A(I) = SIT(I)
  207 PO(I) = SAM(I)
   57 DO 10 I = 1,5
      JJ = I
      IF(ALT .LE. AA(I) .AND. ALT .GT. AA(I+1)) GO TO 20
   10 CONTINUE
   20 IF(JJ .EQ. 3) GO TO 30
      IF(LLL .EQ. 1) GO TO 61
      TAIR = B(JJ) + C(JJ)*ALT
   61 STAIR = B(JJ) + C(JJ)*ALT
      GO TO 131
   30 IF(LLL .EQ. 1) GO TO 65
      TAIR = C(JJ)
   65 STAIR = C(JJ)
  131 KL = 1
      DO 101 I =KL,272
      KL = I
      IF(ALT .LE.  A(I) .AND. ALT .GE.  A(I+1)) GO TO 59
  101 CONTINUE
   59 P = PO(KL+1)-(A(KL+1)-ALT)*(PO(KL+1)-PO(KL))/(A(KL+1)-A(KL))
      RETURN
      END

      SUBROUTINE INTEG(LL,LET,PRES,DEN)
C.....CALCULATES PRESSURE AND DENSITY GIVEN AIR TEMPERATURE
      DIMENSION C(2), D(2) , E(2)
      COMMON /DAT/ ATD(1000), BTMP(1000), CGR(1000)
      COMMON /STD/ A(50), B(50)
      XO = 0.0289644
      R = 8.31432
      IF(LL .LT. LET) GO TO 10
C.....LINEAR INTERPOLATE IN THE RAOB PRESSURE
      DO 20 I = 1,50
      J = I
      IF(ATD(LL) .GE. A(I+1) .AND. ATD(LL) .LE. A(I)) GO TO 70
   20 CONTINUE
   70 PRES = B(J+1)-(A(J+1)-ATD(LL))*(B(J+1)-B(J))/(A(J+1)-A(J))
      DEN = XO*PRES/(R*BTMP(LL))
      RETURN
   10 K1 = LL
      K = LL + 1
      I = 1
C.....INTEGRATE USING OVERLAPPING LAGRANGE POLYNOMIALS
      DO 30 J = K1,K
      IF(J .EQ. LET) GO TO 30
      IF(J .EQ. 1) GO TO 30
      X1 = ATD(J-1)
      X2 = ATD(J)
      X3 = ATD(J+1)
      TERM1 = CGR(J-1)*XO/(R*BTMP(J-1))/((X1-X2)*(X1-X3))
      TERM2 = CGR(J)*XO/(R*BTMP(J))/((X2-X1)*(X2-X3))
      TERM3 = CGR(J+1)*XO/(R*BTMP(J+1))/((X3-X1)*(X3-X2))
      C(I) = TERM1 + TERM2 + TERM3
      D(I) = -(X2+X3)*TERM1-(X1+X3)*TERM2-(X1+X2)*TERM3
      E(I)=X2*X3*TERM1+X1*X3*TERM2+X1*X2*TERM3
   30 I = I + 1
      IF(K .NE. LET) GO TO 40
      C(2) = C(1)
      D(2) = D(1)
      E(2) = E(1)
   40 IF(K1 .NE. 1) GO TO 90
      C(1) = C(2)
      D(1) = D(2)
      E(1) = E(2)
   90 XINT=(C(1)+C(2))*(ATD(K1)**3-ATD(K)**3)/6.0+(D(1)+D(2))*
     1(ATD(K1)**2-ATD(K)**2)/4.0+(E(1)+E(2))*(ATD(K1)-ATD(K))/2.0
      PRES = PRES*EXP(-XINT)
      DEN = XO*PRES/(R*BTMP(LL))
      RETURN
      END

      SUBROUTINE INITAL
      COMMON /ANT/ T(100),X(100,4),XBAR(100,4),XDOT(100,4),XDDOT(10
      COMMON /ANT/ MF,MB,ML,MS,MK,MJ,MN,N,IQ,TAP,TP,TMLTP
      DIMENSION S6(4),S7(4),S8(4),XSMALL(4)
      MJ = MB + 1
      MS = MJ - MB
      MK = MJ + 1
      MN = MJ + MF - 1
      ML = MN + 1
      MPP = ML
      TMLTP = T( ML ) - T( MN )
      TP=T(MJ)
      TAP = T(MJ) - T(MS)
      PA = 1.75
      S1=0.
      S2=0.
      S3=0.
      S4=0.
      S5=0.
      S9=0.
      DO 120 I = 1,N
      S6(I) = 0.0
      S7(I) = 0.0
  120 S8(I) = 0.0
      DO 2778 J = 1,MF
      DIFT = T(J) - T(1)
      DO 122  I = 1, N
      S6(I) = S6(I) + X(J,I)
      S7(I) = S7(I) + DIFT * X(J,I)
  122 S8(I) = S8(I) + .5 * DIFT **2 *X(J,I)
      S1 = 1. + S1
      S2 = S2 + DIFT
      S3 = S3 + DIFT **2
      S9 = S3 *.5
      S4 = S4 + DIFT **3 *.5
 2778 S5 = S5 + DIFT **4 *.25
      DD = S1*S3*S5 + 2.*S2*S9*S4 - S3*S9**2 - S1*S4**2 - S5*S2**2
```

```
      COF1 = S3*S5 - S4**2
      COF2 = S9*S4 - S2*S5
      COF3 = S2*S4 - S3*S9
      COF4 = S1*S5 - S9**2
      COF5 = S2*S9 - S1*S4
      COF6 = S1*S3 - S2**2
      DO 133  I = 1, N
      XBAR(1,I)= ( COF1 * S6(I)  +  COF2*S7(I) + COF3*S8(I))/ DD
      XDOT(1,I) = ( COF2*S6(I) + COF4*S7(I) + COF5*S8(I)) / DD
      XDDOT(1,I) = (COF3*S6(I) + COF5*S7(I) + COF6*S8(I)) /DD
      DELT = T(2) - T(1)
      XBAR(2,I) = XBAR(1,I) + DELT*XDOT(1,I)  + .5*XDDOT(1,I)*DELT**2
  133 XDOT(2,I) = XDOT(1,I) + DELT*XDDOT(1,I)
      DO 1002 NR = 2,MJ
      NR1 = NR + 1
      MMR = MF + NR
      S2 = 0.
       T0 = T(NR)
      DO 144  I = NR1, MMR
  144 S2 = S2 + ( T(I) - T0) **4
      DO 155  I = 1, N
      S1 = 0.
      DO 166  J = NR1, MMR
      DIFT = T(J) - T0
      XSMALL(1) = X(J,I) - XBAR(NR,I) - XDOT(NR,I) * DIFT
  166 S1 = S1 + XSMALL(1) * DIFT**2
      DNU = 2.*XDDOT(NR-1,I)*PA**2 + S1
      DDE= 2. * PA **2 + .5 *S2
      XDDOT(NR,I) = DNU/ DDE
      IF(NR.EQ.MJ) GO TO 155
      DELT = T(NR1) - T(NR)
      XBAR(NR1,I) = XBAR(NR,I) + DELT*XDOT(NR,I)+ .5*XDDOT(NR,I)*DELT**2
      XDOT(NR1,I) = XDOT(NR,I) + XDDOT(NR,I)*DELT
  155 CONTINUE
 1002 CONTINUE
      DO 1003  J = MK , ML
      DIFT = T(J) - T(MJ)
      DO 1003  I = 1, N
      XDDOT(J,I) = XDDOT(MJ,I)
      XDOT(J,I) = XDOT(MJ,I) + DIFT*XDDOT(MJ,I)
 1003 XBAR(J,I) = XBAR(MJ,I) + DIFT*XDOT(MJ,I) + .5*XDDOT(MJ,I)*DIFT**2
      MDR=ML+1
      DO 2125 JL =1,4
      DO 2123 J=1,MDR
      PRINT 2122,J,T(J),X(J,JL),XBAR(J,JL),XDOT(J,JL),XDDOT(J,JL)
 2123 CONTINUE
 2125 CONTINUE
 2122 FORMAT (1H ,I3,5X,F5.1,5X,4F20.7 )
      RETURN
      END

      SUBROUTINE DIRSIT
      DIMENSION TDIF(200),DIFF(200),NDEX(200)
      COMMON /ANT/ T(100),X(100,4),XBAR(100,4),XDOT(100,4),XDDOT(100,4)
      COMMON /ANT/ MF,MB,ML,MS,MK,MJ,MN,N,IQ,TAP,TP,TMLTP
      COMMON /DIST/ TOO,XR,XS,XD,XDD,YR,YS,YD,YDD,ZR,ZS,ZD,ZDD,TE,TD,II
      COMMON /DIST/ TER,TDD
      K = 1
      TMLTP = T(ML) - T(MN)
      DO 9 INDEX = 1,2
      MJ = MB + 1
      MS = MJ - 1
      MK = MJ + 1
   31 CONTINUE
      TP  = T( MJ )
      TAP = T(MJ) - T(MS)
   32 NS=0
      NL=0
      DO 50 I=MK,ML
      DELX=X(I,K)-XBAR(I,K)
      IF(DELX.LT.0.)GO TO 40
      NS=NS+1
      DIFF(NS) = DELX
      TDIF(NS) = T(I)
      NDEX(NS) = I
      GO TO 50
   40 NL=NL+1
      NZ1 = NL + MF
      DIFF(NZ1)=DELX
      TDIF(NZ1)=T(I)
      NDEX(NZ1) = I
   50 CONTINUE
      IF(II.EQ.1) GO TO 5
      PRINT 10, NL,NS
   10 FORMAT (8H TEST 1     , 2I5  )
    5 CONTINUE
      IF ( IABS( NL - NS ) . LE . IQ)  GO TO 200
      IF ( NL . LT . NS ) GO TO 110
      NT = NL + MF
      LLI = MF + 1
      SGN=-1.
      GO TO 1005
  110 NT=NS
      LLI = 1
      SGN=1.
 1005 SS=1000000.
      IF(II.EQ.1) GO TO 6
      PRINT 1, SGN,TAP,NL,NS
    1 FORMAT (8H STEP 1    ,2F15.5, 2I5)
    6 CONTINUE
  145 DO 1111 IX=LLI,NT
      SL = 6. * SGN * DIFF(IX) / ( ( TDIF(IX) - T(MS))**3 - ( TDIF(IX)
     1 - TP ) ** 3 )
      IF ( SL . GT . SS ) GO TO 1111
      SS=SL
      MI = IX
 1111 CONTINUE
      TCOR = TDIF(MI)
      TBAR = T( MS )
      IR = MS
  185 SS=SGN*SS
      IF(II.EQ.1) GO TO 7
      PRINT 2, NS,MI,TCOR,SS,TBAR
    2 FORMAT (8H STEP 2  ,2I5,F15.5,E20.10,F15.5    )
    7 CONTINUE
      DO 190 I=IR,MJ
      TEMP=T(I)-T(MS)
      XDDOT(I,K)=XDDOT(I,K)+SS*TEMP
      XDOT (I,K)= XDOT(I,K)+SS*TEMP**2/2.
  190 XBAR (I,K)= XBAR(I,K)+SS*TEMP**3/6.
      POLY1=SS*TAP
      POLY2=SS*TAP*TAP*TAP/6.
      POLY3=SS*TAP*TAP/2.
      DO 195 I=MK,ML
      XDDOT(I,K)=XDDOT( I,K)         +POLY1
      TITP=T(I)-TP
      XDOT (I,K)=XDOT(I,K)+POLY1*TITP+POLY3
```

```
      IF(T(I).EQ.TCOR)GO TO 193
      XBAR(I,K)=XBAR(I,K)+POLY2+POLY3*TITP+POLY1*TITP**2/2.
      GO TO 195
  193 XBAR(I,K) = X(I,K) + SGN * ( .2982E-07 )* ABS( X(I,K) )
  195 CONTINUE
      DO 2121 I=LLI,NT
      NDIX=NDEX(I)
      IF((X(NDIX,K) - XBAR(NDIX,K))*SGN.GT.0.) GO TO 2121
      IF(I.NE.MI)XBAR(NDIX,K)=X(NDIX,K)-SGN*(.2982E-07)*ABS(X(NDIX,K))
 2121 CONTINUE
      GO TO 32
  200 CONTINUE
      NVB = K
      K = K +1
      IF(K.LE.N) GO TO 31
      MB = MB + 10
    9 CONTINUE
      TOO = T(1)
      XR = X(1,1)
      XS = XBAR(1,1)
      XD = XDOT(1,1)
      XDD = XDDOT(1,1)
      YR = X(1,2)
      YS = XBAR(1,2)
      YD = XDOT(1,2)
      YDD = XDDOT(1,2)
      ZR = X(1,3)
      ZS = XBAR(1,3)
      ZD = XDOT(1,3)
      ZDD = XDDOT(1,3)
      TER = X(1,4)
      TE = XBAR(1,4)
      TD = XDOT(1,4)
      TDD = XDDOT(1,4)
      DO 206 K =1,NVB
      DO 205 I=1,MN
      X(I,K)=X(I+1,K)
      XBAR(I,K)=XBAR(I+1,K)
      XDOT(I,K)=XDOT(I+1,K)
      XDDOT(I,K)=XDDOT(I+1,K)
  205 CONTINUE
  206 CONTINUE
      DO 207 I = 1,MN
      T(I) = T(I+1)
  207 CONTINUE
      DO 220 K = 1,NVB
      J=ML
      XBAR(J,K) = XBAR(J-1,K) + TMLTP*XDOT(J-1,K) + TMLTP*TMLTP*XDDOT(J
     1-1,K) * .5
      XDOT(J,K) = XDOT(J-1,K) + TMLTP*XDDOT(J-1,K)
  221 XDDOT(J,K) = XDDOT(J-1,K)
  220 CONTINUE
      IF(II.EQ.1) GO TO 8
      DO 2125 JL =1,4
      DO 3 J=1,ML
      PRINT 2122,J,T(J),X(J,JL),XBAR(J,JL),XDOT(J,JL),XDDOT(J,JL)
    3 CONTINUE
 2125 CONTINUE
 2122 FORMAT (1H ,I3,5X,F5.1,5X,4F20.7 )
      II = 1
    8 CONTINUE
      RETURN
      END
```



```
      SUBROUTINE HANDR(IK)
      COMMON /AP/ ZOT, TINF, RHO, VS, AMU, AK, AMFP, VEL, TAIR
      COMMON /RFAC/ ZSR(15), ZRB(15), ZRW(15)
      COMMON /REG/ IC, IS, IT, IF
      COMMON /CLEN/ CLB,CLW,CLF,CLFILM
      COMMON /HR/ HB,HW,HF,RB,RW,RF
      COMMON /XXY/ IRB, IRW, IRF
      COMMON /YL/ P
      DATA CP/1003./
      DATA ACB, ACW, ACF/0.9, 0.9, 0.9/
      XO = .0289644
      R = 8.31432
      AMU = 1.458E-06*TAIR**(3./2.)/(TAIR+110.4)
      AK = 6.325E-07*TAIR**(3./2.)/(TAIR+245.4*10.**(-12./TAIR))
      AK = AK*4186.0465
      VS = SQRT(1.4*R*TAIR/XO)
      RHO = P*XO/(R*TAIR)
      AMFP = R*TAIR/(P*(2.**.5)*3.1415926*6.02257E+26*(3.65E-10)**2)
      AMFP = AMFP*1.E+03
      IF(IK .EQ. 1) GO TO 12
      AM=VEL/VS
      SR=0.837*AM
      PR=CP*AMU/AK
      ARB=1.167
      ARW=1.167
      IF (SR .GT. 10.) GO TO 2
      DO 1 I=1,13
      DSR=ZSR(I)-SR
      IF (DSR .LT. 0.) GO TO 1
      ERRR=DSR/(ZSR(I)-ZSR(I-1))
      DIFFRB=ZRB(I)-ZRB(I-1)
      DIFFRW=ZRW(I)-ZRW(I-1)
      CORRRB=ERRR*DIFFRB
      CORRRW=ERRR*DIFFRW
      ARB=ZRB(I)-CORRRB
      ARW=ZRW(I)-CORRRW
      GO TO 2
    1 CONTINUE
    2 REB=RHO*VEL*CLB/AMU
      AMRB=AM/REB
      AMSRB=AM/SQRT(REB)
      IRB=IC
      IF (REB .LE. 1. .AND. AMRB .GT. 0.01) IRB=IS
      IF (REB .LE. 1. .AND. AMRB .GT. 0.1) IRB=IT
      IF (REB .GT. 1. .AND. AMSRB .GT. 0.01) IRB=IS
      IF (REB .GT. 1. .AND. AMSRB .GT. 0.1) IRB=IT
      IF (AMRB .GT. 3.) IRB=IF
      AKNB=AMFP/CLB
      RB=0.85+(AKNB*(ARB-0.85))/(AKNB+0.3)
      IF (IRB .NE. IF .AND. IRB .NE. IT) GO TO 4
      FHB=289.*ACB*VS*RHO
      IF (SR .LT. 1.E-8) GO TO 3
      T=1./(1.+0.3275911*SR)
      ERFA=0.254829592*T-0.284496736*T**2+1.421413741*T**3
      ERFB=-1.453152027*T**4+1.061405429*T**5
      ERF=1.-(ERFA+ERFB)*EXP(-SR**2)
      FHB=0.44311*FHB*((2.*SR+1./SR)*ERF+1.12838*EXP(-SR**2))
    3 HB=FHB
      IF (IRB .EQ. IF) GO TO 5
    4 ANUCB=2.+0.37*REB**0.6*PR**0.333
      HB=ANUCB*AK/CLB
      IF (IRB .EQ. IC) GO TO 5
      ANUSB=ANUCB/(1.+3.42*ANUCB*AM/(REB*PR))
      SHB=ANUSB*AK/CLB
```

```
      HB=SHB
      IF (IRB .EQ. IS) GO TO 5
      IF (AMRB .LT. 1.) GO TO 5
      Y=0.91024*ALOG(AMRB)
      HB=Y*FHB+(1.-Y)*SHB
    5 REW=RHO*VEL*CLW/AMU
      AMRW=AM/REW
      AMSRW=AM/SQRT(REW)
      IRW=IC
      IF (REW .LE. 1. .AND. AMRW .GT. 0.01) IRW=IS
      IF (REW .LE. 1. .AND. AMRW .GT. 0.1) IRW=IT
      IF (REW .GT. 1. .AND. AMSRW .GT. 0.01) IRW=IS
      IF (REW .GT. 1. .AND. AMSRW .GT. 0.1) IRW=IT
      IF (AMRW .GT. 3.) IRW=IF
      AKNW=AMFP/CLW
      RW = 0.845 + (AKNW*(ARW - 0.845))/(AKNW + 0.3)
      IF (IRW .NE. IF .AND. IRW .NE. IT) GO TO 7
      T=0.5*SR**2
      Z=T/3.75
      IF (Z .GT. 1.) PRINT 6
    6 FORMAT(1H ,51HVELOCITY TOO LARGE FOR BESSEL FUNCTION APPROXIMATOR)
      BM0A=1.+3.5156229*Z**2+3.0899424*Z**4+1.2067492*Z**6
      BM0B=0.2659732*Z**8+0.0360768*Z**10+0.0045813*Z**12
      BM0=BM0A+BM0B
      BM1TA=0.5+0.87890594*Z**2+0.51498869*Z**4+0.15084934*Z**6
      BM1TB=0.02658733*Z**8+0.00301532*Z**10+0.00032411*Z**12
      BM1T=BM1TA+BM1TB
      HWA=289.*ACW*VS*RHO*EXP(-T)
      HWB=(1.+2.*T)*BM0+2.*T**2*BM1T
      FHW=HWA*HWB
      HW=FHW
      IF (IRW .EQ. IF) GO TO 12
    7 CONTINUE
      ANUCW=2.+0.37*(REW**0.6)*(PR**0.333)
      ANUSW=ANUCW/(1.+3.42*ANUCW*AM/(REW*PR))
      SHW=ANUSW*AK/CLW
      HW=SHW
      IF(IRW.EQ.IS) GO TO 120
      IF(AMRW.LT.1.0) GO TO 120
      Y=0.91024*ALOG(AMRW)
      HW=Y*FHW+(1.-Y)*SHW
  120 CONTINUE
      IF(AMSRW.GT.0.03) GO TO 12
    8 IF (REW .GT. 4000.) GO TO 9
      CHW=(AK/CLW)*(0.43+0.48*REW**0.5)
      GO TO 11
    9 IF (REW .GT. 40000.) GO TO 10
      CHW=(AK/CLW)*(0.43+0.174*REW**0.618)
      GO TO 11
   10 CHW=(AK/CLW)*(0.43+0.0239*REW**0.805)
   11 HW=CHW
      RW = 0.845
      IF(AMSRW.LT.0.003) GO TO 12
      QUAN = 1000.0*AMSRW
      Y = ALOG10(QUAN) - 0.48
      HW = Y * SHW + (1. - Y) * CHW
   12 REF=RHO*VEL*CLF/AMU
      AMRF=AM/REF
      AMSRF=AM/SQRT(REF)
      IRF=IC
      IF (REF .LE. 1. .AND. AMRF .GT. 0.01) IRF=IS
      IF (REF .LE. 1. .AND. AMRF .GT. 0.1) IRF=IT
      IF (REF .GT. 1. .AND. AMSRF .GT. 0.01) IRF=IS
      IF (REF .GT. 1. .AND. AMSRF .GT. 0.1) IRF=IT
      IF (AMRF .GT. 3.) IRF=IF
      IF (IRF .NE. IF .AND. AMRF .LT. 1.) GO TO 13
      RFF=1.167
      RF=RFF
      FHF=289.*ACF*VS*RHO
      HF=FHF
      IF (IRF .EQ. IF) GO TO 17
   13 AKNF=AMFP/CLF
      AKNFT=AKNF*(SQRT(REF)/7.2)
      RFT = 0.845 + (AKNFT*0.322)/(AKNFT + 0.3)
      RF=RFT
      X2=(REF*PR)/(6.9*AM**2)
      X=SQRT(X2)
      IF (X .GT. 2.5) GO TO 14
      T=1./(1.+0.3275911*X)
      ERFA=0.254829592*T-0.284496736*T**2+1.421413741*T**3
      ERFB=-1.453152027*T**4+1.061405429*T**5
      ERFX=(ERFA+ERFB)*EXP(-X2)
      ANUF=(EXP(X2)*ERFX-1.+1.1283792*X)*AM*2.62
      GO TO 15
   14 ANUF=((0.5641896/X)-1.+1.1283792*X)*AM*2.62
   15 SHF=(AK/CLF)*ANUF
      HF=SHF
      IF (AMRF .LT. 1.) GO TO 16
      Y=0.91024*ALOG(AMRF)
      RF=Y*RFF+(1.-Y)*RFT
      HF=Y*FHF+(1.-Y)*SHF
      GO TO 17
   16 IF(AMSRF.GT.0.03) GO TO 17
      IF(AMSRF.GT.0.003) GO TO 260
      RF = 0.845
      HF = (AK/CLF)*.664*(REF**.5)*(PR**.333)
      GO TO 17
  260 CONTINUE
      QUAN = 1000. * AMSRF
      Y = ALOG10(QUAN) - 0.48
      IF(IRF.EQ.IC) RF = .845
      CHF = (AK/CLF)*0.664*(REF**0.5)*(PR**0.333)
      HF = Y * HF + (1.0 - Y) * CHF
   17 CONTINUE
      RETURN
      END
```

25000.00 METERS

ATMOSPHERIC PARAMETERS

ALTITUDE(METER)=	.24992+05
SENSOR TEMP(DEG K)=	218.4
PRESSURE(NEWTON/M**2)=	.2552+04
DENSITY(KGM/M**3)=	.4081-01
VELOCITY OF SOUND(M/SEC)=	295.9
VISCOSITY(KGM/(M*SEC))=	.1428-04
HERMAL CONDUCTIVITY(WATTS/METER)=	.1962-01
MEAN FREE PATH(METER)=	.1991-05

HEAT CONDUCTION PARAMETERS

	BEAD	WIRE	FILM	SENSOR
HK(WATTS/(M**2*DEG K))=				237.3
K1=				.9992
K2(DEG K)=				.4375
LAMDA(1/METER)=		2510.	148.4	
3*DECAY LENGTH(METER)=		.1195-02	.2022-01	
CONDUCTION TEMP CORRECTION(DEG K)=				-.153

AERODYNAMIC HEATING PARAMETERS

	BEAD	WIRE	FILM	SENSOR
CONV COEF(WATTS/(M**2*DEG K))=	213.9	1220.	23.44	
RECOVERY COEFICIENT=	.8643	1.034	.8450	
FLOW REGION=	S	S	C	
AERODYN HEAT(DEG K)=	.1211	.1449	.1184	
AERODYNAMIC TEMP CORRECTION(DEG K)=				-.574-01

DYNAMIC LAG PARAMETERS

	BEAD	WIRE	FILM	SENSOR
TIME CONSTANT(SEC)=	.4856	.1497-02	.5657	.2303
TEMPERATURE(DEG K)=	218.4	218.3	219.4	
EQUILIBRIUM TEMP(DEG K)=	218.6	218.1	219.4	218.4
AK(I)=	.9989	.9998	.9505	
BK(I)(DEG K)=	.9537	.2952	12.50	
TEMP TIME DER(DEG K/SEC)=				-.535-01
DYNAMIC TEMP LAG CORRECTION(DEG K)=				-.123-01

RADIATION HEATING PARAMETERS

	BEAD	WIRE	FILM	SENSOR
TOTAL RADIATION INPUT(W/M**2)=	119.7	144.8	99.50	
RADIATION TEMP CORRECTION(DEG K)=				-.237

ELECTRIC HEATING PARAMETERS

	BEAD	WIRE	FILM	SENSOR
ELECTRIC HEATING(WATTS/M**2)=				20.0
ELECTRIC TEMP CORRECTION(DEG K)=				-.443-01

35000.00 METERS

ATMOSPHERIC PARAMETERS

ALTITUDE(METER)=	.34993+05
SENSOR TEMP(DEG K)=	237.0
PRESSURE(NEWTON/M**2)=	.5752+03
DENSITY(KGM/M**3)=	.8503-02
VELOCITY OF SOUND(M/SEC)=	307.7
VISCOSITY(KGM/(M*SEC))=	.1524-04
HERMAL CONDUCTIVITY(WATTS/METER)=	.2110-01
MEAN FREE PATH(METER)=	.9555-05

HEAT CONDUCTION PARAMETERS

	BEAD	WIRE	FILM	SENSOR
HK(WATTS/(M**2*DEG K))=				158.7
K1=				.9902
K2(DEG K)=				3.634
LAMDA(1/METER)=		1679.	136.0	
3*DECAY LENGTH(METER)=		.1787-02	.2205-01	
CONDUCTION TEMP CORRECTION(DEG K)=				-.651

AERODYNAMIC HEATING PARAMETERS

	BEAD	WIRE	FILM	SENSOR
CONV COEF(WATTS/(M**2*DEG K))=	160.8	545.5	19.93	
RECOVERY COEFICIENT=	.9136	1.347	.8455	
FLOW REGION=	S	T	C	
AERODYN HEAT(DEG K)=	.7363	1.085	.6814	
AERODYNAMIC TEMP CORRECTION(DEG K)=				-.372

DYNAMIC LAG PARAMETERS

	BEAD	WIRE	FILM	SENSOR
TIME CONSTANT(SEC)=	.6456	.3346-02	.6500	.3252
TEMPERATURE(DEG K)=	237.0	236.9	236.8	
EQUILIBRIUM TEMP(DEG K)=	237.1	237.0	236.8	237.0
AK(I)=	.9981	.9994	.9284	
BK(I)(DEG K)=	1.935	1.449	17.98	
TEMP TIME DER(DEG K/SEC)=				-.268
DYNAMIC TEMP LAG CORRECTION(DEG K)=				-.878-01

RADIATION HEATING PARAMETERS

	BEAD	WIRE	FILM	SENSOR
TOTAL RADIATION INPUT(W/M**2)=	119.7	144.8	99.50	
RADIATION TEMP CORRECTION(DEG K)=				-.320

ELECTRIC HEATING PARAMETERS

	BEAD	WIRE	FILM	SENSOR
ELECTRIC HEATING(WATTS/M**2)=				20.0
ELECTRIC TEMP CORRECTION(DEG K)=				-.629-01

50000.00 METERS

ATMOSPHERIC PARAMETERS

ALTITUDE(METER)=	.49986+05
SENSOR TEMP(DEG K)=	280.0
PRESSURE(NEWTON/M**2)=	.7992+02
DENSITY(KGM/M**3)=	.1061-02
VELOCITY OF SOUND(M/SEC)=	324.8
VISCOSITY(KGM/(M*SEC))=	.1663-04
HERMAL CONDUCTIVITY(WATTS/METER)=	.2330-01
MEAN FREE PATH(METER)=	.7661-04

HEAT CONDUCTION PARAMETERS

	BEAD	WIRE	FILM	SENSOR
HK(WATTS/(M**2*DEG K))=				68.39
K1=				.7907
K2(DEG K)=				73.06
LAMDA(1/METER)=		707.9	128.1	
3*DECAY LENGTH(METER)=		.4238-02	.2343-01	
CONDUCTION TEMP CORRECTION(DEG K)=				-8.20

AERODYNAMIC HEATING PARAMETERS

	BEAD	WIRE	FILM	SENSOR
CONV COEF(WATTS/(M**2*DEG K))=	66.45	96.55	15.75	
RECOVERY COEFICIENT=	1.149	1.610	.8539	
FLOW REGION=	T	T	S	
AERODYN HEAT(DEG K)=	14.17	19.85	10.53	
AERODYNAMIC TEMP CORRECTION(DEG K)=				-7.81

DYNAMIC LAG PARAMETERS

	BEAD	WIRE	FILM	SENSOR
TIME CONSTANT(SEC)=	1.554	.1882-01	.7747	.7685
TEMPERATURE(DEG K)=	280.0	277.2	269.5	279.5
EQUILIBRIUM TEMP(DEG K)=	278.3	283.5	269.6	
AK(I)=	.9926	.9950	.8743	
BK(I)(DEG K)=	17.71	22.29	40.14	
TEMP TIME DER(DEG K/SEC)=				-.359
DYNAMIC TEMP LAG CORRECTION(DEG K)=				-.310

RADIATION HEATING PARAMETERS

	BEAD	WIRE	FILM	SENSOR
TOTAL RADIATION INPUT(W/M**2)=	119.7	144.8	99.50	
RADIATION TEMP CORRECTION(DEG K)=				-.704

ELECTRIC HEATING PARAMETERS

	BEAD	WIRE	FILM	SENSOR
ELECTRIC HEATING(WATTS/M**2)=				20.0
ELECTRIC TEMP CORRECTION(DEG K)=				-.166

APPENDIX B

SENSOR PARAMETERS

The following is a list of input parameters for the ARCAS bead-wire-film temperature sensor as contained in various references.

Thermistor		
Parameter	Value	Reference
D	$.32 \cdot 10^{-3}$ m	19
ρ	$3.9 \cdot 10^{3}$ kg/m^{3}	17
C	$5.0 \cdot 10^{2}$ J/(kg°K)	17
ε_L	.10	17
ε_S	.16	17

Platinum (90% - Iridium (10%) wire		
Parameter	Value	Reference
D	$.25 \cdot 10^{-4}$ m	19
ρ	2161 kg/m^{3}	7
C	135.2 J/(kg°K)	7
k	30.98 J/(mS°K)	7
ε_L	.10	17
ε_S	.19	17
ℓ	.0032 m	1

Silver film		
Parameter	Value	Reference
D	$.4 \cdot 10^{-5}$ m	1
ρ	$10.5 \cdot 10^{3}$ kg/m^3	5, 7
C	233.6 J/(kg°K)	7
k	407.7 J/(S°Km)	7
ε_L	.02	20
ε_S	.01	15
ℓ inner	.03 m	1
ℓ outer	.036 m	1

Mylar film		
Parameter	Value	Reference
D	$.25 \cdot 10^{-4}$ m	1
ρ	$1.394 \cdot 10^{3}$ kg/m^3	8
C	$1.32 \cdot 10^{3}$ J/(kg°K)	8
k	.152 J/(s°Km)	8
ε_L	.451	15
ε_S	.0281	15

A procedure is discussed next for calculating the emissivity over the entire film. The outer legs of the film strip consist of a composite silver-mylar layer. The total emissivity of this strip can be computed from the following equation.

$$\varepsilon_{My-Ag} = \varepsilon_{My} + \left(1 - \alpha_{My}\right)\left[\left(1 - \alpha_{Ag}\right) \varepsilon_{My} + \varepsilon_{Ag}\right]^{19} \tag{61}$$

For long wave radiation, the emissivities are

$$\varepsilon_{My} = .451 \ , \ \varepsilon_{Ag} = .02 \ , \ \varepsilon_{My-Ag} = .710$$

For short wave radiation, the emissivities are

$$\varepsilon_{My} = .028 \ , \ \varepsilon_{Ag} = .01 \ , \ \varepsilon_{My-Ag} = .065$$

The inner film strip has the radiation emission properties of silver. In order to determine an effective emissivity over the entire film, the emissivities of the inner and outer film strips are averaged together, using their lengths as weighting factors.

$$\varepsilon_{fL} = \left[2\left(.710\right) .036 \text{ m} + .02 \left(.03 \text{ m}\right)\right] \Big/ \left[2\left(.036 \text{ m}\right) + .03 \text{ m}\right] = .51$$

$$\varepsilon_{fS} = \left[2\left(.065\right) .036 \text{ m} + .01 \left(.03 \text{ m}\right)\right] \Big/ \left[2\left(.036 \text{ m}\right) + .03 \text{ m}\right] = .05$$

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